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HOUSE OF REPRESENTATIVES, UNITED STATES
COMMITTEE ON AGRICULTURE

A REPORT

ON

"THE INFLUENCE OF FORESTS ON CLIMATE AND ON FLOODS"

BY

WILLIS L. MOORE, LL. D., Sc. D
Chief of the U. S. Weather Bureau

NOTE.—When Professor Willis L. Moore was before the Committee on Agriculture of the House of Representatives in 1909, to explain the estimates for the Weather Bureau, a discussion arose as to the influence of forests on climate and on the run-off of water. Professor Moore stated that he was then making some studies on the subject which might lead to some definite conclusions, and he was requested by the chairman of the committee to continue these studies and make a report when they were concluded. This has been done, and the report submitted by Professor Moore, which follows, is printed by direction of the committee.

WASHINGTON
GOVERNMENT PRINTING OFFICE
1910

THE INFLUENCE OF FORESTS ON CLIMATE AND ON FLOODS.

By Willis L. Moore, LL. D., Sc. D., *Chief U. S. Weather Bureau.*

INTRODUCTION.

One of the most important problems before the American people to-day is the protection of their natural resources against either the greed of those who would monopolize them for their own individual benefit or those who, while well meaning, would through ignorance destroy our heritage and leave posterity poor.

In the discussion of matters concerned with the conservation of the natural resources of the nation, some of which may involve the expenditure of hundreds of millions of dollars and the employment for years to come of thousands of public officials, a consideration of the relation of forests to climate, floods, and low water is vitally important.

While much has been written on this subject, but little of it has emanated from meteorologists or from those in the public service who have been actively engaged in the forecasting of river stages, both of high and of low water. In the prosecution of such duty these officials have become acquainted with the physical facts involved in the problem and are therefore well fitted to speak on the relation of such facts to stream flow.

THE AUTHOR ACKNOWLEDGES A CHANGE OF OPINION.

It has frequently been stated that forests control the flow of streams, both in high-water stages and in low-water stages, and that the climate is so materially affected by the cutting away of the forests that droughts have largely increased and that the well-being of future generations is seriously menaced. It is my purpose to present facts and figures that do not support these views, some of which, especially those that pertain to the flow of streams, were held by me up to a few years ago—until a careful study of our own and other records and of the incidents of history caused me to modify my opinions. I shall endeavor not to be dogmatic, but rather to present the reasons for the conclusions that I now entertain, with, so far as may be, statistical and historical evidence to sustain them. And I reserve the right to change or still further modify my views if the presentation of new facts and figures render such a course logical, and do not consider that I shall stultify myself in so doing.

FORESTS SHOULD BE PROTECTED.

There are so many reasons why forests should be protected by the state and the nation and economically conserved in the interests of the whole people that it is doing an injury to a good cause to attempt to bring to its support the false reasoning and mistaken conclusions of enthusiasts, no matter how well meaning they may be or how devoted to high and lofty purposes.

Conservation of national resources is national economy, just as conservation of private resources is personal economy. But whether personal economy is beneficial or harmful to the individual and his children depends upon the extent and nature of that economy; and the same thing is equally true of a nation. Conservation that prevents the practical use of individual or national resources is like unto the economy of the timid servant that hid his master's talent in the earth, and in large measure deserves the same condemnation.

There should be neither wasteful use of resources nor that greatest waste of all, total disuse of them, but that economical use which in the end will have yielded the greatest good to the greatest number.

Preservation of the forests, cutting wisely, but never more than they reproduce, enables us to draw from a perpetual supply a certain quantity of material for buildings, for furniture, and for fuel. But of course the *forested land yields not a handful of wheat nor of corn and makes but a wretched substitute for the pasture upon which to feed milch cows and beef cattle.* These conflicting interests, the pleading of the poor man's children for bread and meat and the cry of the country for the lumber that only a woodland can furnish would, if there were no other interests to modify the result, somewhere find an inevitable balance. But just as the body is more important than its raiment, so, too, is its food more important than its shelter; and therefore in every country *the general tendency, with growth of population, is to convert forest lands into cultivated fields, and this tendency should not be discouraged unless it can be shown that deforestation has augmented droughts and floods, and I believe that it can not be so shown; I believe that forests should be preserved for themselves alone, or not at all.*

The average virgin forest is wasteful as a source of lumber and of fuel. It is only here and there that a tree is found of proper growth and suitable species for first-class material. As a lumber producer a forest of this kind is analogous to a cornfield planted in scattering hills here and yonder, instead of being cultivated throughout its extent and planted with that regularity and closeness of spacing that will produce the maximum yield. If the expense is not found to be too great in comparison with the return, forests should be cultivated with the same care both as to species and as to distribution, and possibly, too, as to rotation, that the intelligent farmer uses in planting his fields. In this way returns equal to what we now get could be secured from a much smaller forested area, and *there can be no valid objection to decreasing the area where homes and a well-fed people take the place of wild animals and the wilderness.*

It is found that in some limited areas where the forest is cleared away, the soil, owing to its nature and slope, will not admit of successful cultivation. It may wash so badly under heavy rains as to become unfit even for reforesting. In others, owing to the nature

of the surface, cultivation is impossible. These are fit places for local control, provided such control is commercially feasible, but not for national control, *unless it can be demonstrated that the conditions at these places materially affect the navigability of streams or harmfully affect the climate of the continent at large.*

The great value of forests as fuel producers is admitted on every hand, and because of the growing cost of coal their importance in this particular is likely to increase rather than diminish, and of course without them the world would be deprived of that beautiful building material which from the earliest ages it has used so freely and regarded as indispensable, but which in the future may be used in a less ratio as the use of noncombustible materials, like concrete, stone, and steel, becomes more general, and certainly their use will increase. No reason in addition to these can be needed to justify an immediate and vigorous effort on the part of individuals, and especially on the part of governments, to teach and to insure the wisest national use—that is, wisest use when both the present and the future are properly considered—of all existing forests, and also where and how best to secure other forested areas.

Nevertheless additional reasons are urged, and in some cases urged as the paramount reasons for forest conservation, which will not stand the test of investigation.

EFFECT OF FOREST ON CLIMATE.

It is often said that the climate of a given place depends upon the extent and proximity of wooded areas; that the number of rainy days and the total amount of rainfall are modified by change of forest extent; that the depth of floods, the shallowness of low water, and the regularity of flow are all profoundly modified by changing the proportion of fields to forests in the watershed.

Now, the extent and even the nature of these influences is not a matter, as often is implied, of universal agreement. In regard to change of climate, regardless of the cause, trustworthy records of temperature, of rainfall, and of other meteorological elements do not cover a sufficient range of time to furnish all the data necessary for a *statistical* solution of this problem. However, there appears to be plenty of evidence that there have been times in the remote past when the salt seas both of Asia and of America had surfaces of greatly increased size over those that now exist. There is evidence also that in certain of these regions trees once grew more abundantly than is now the case. This, however, must not be taken as proof that there has been a decrease of rainfall due to destruction of the forests. It is true that the forests have diminished—in some cases wholly vanished—and it is also true that the evidence strongly supports the assumption of a decrease in rainfall, and therefore, of course, of a greater or less change of climate; but this decrease of precipitation might better be regarded as the cause rather than as the result of the barren condition of the soil. There is no evidence that the forests were ever more extensive in Alaska and in other high-latitude countries than they now are. Nevertheless, in these countries, too, just as in arid regions of the great continents, there is evidence of the same slow, long-period climatic change—a decrease of precipitation or an increase of temperature, or both—a change that can

not be due to deforestation. This evidence consists in the slow irregular retreat (followed once in a while by a slight advance) and diminution of the glaciers, which phenomenon is said to be universal regardless of latitude, of longitude, and of elevation, and which appears to have been in more or less steady progress with, however, occasional temporary relapses of one or another magnitude since the culmination of the great ice age. In fact, we can reasonably say that we are even yet in the ice age—a vanishing age to be sure, but one not wholly gone—*and, further, that whatever marked climatic changes take place they are essentially universal and not local.*

Prof. William J. Humphreys, Ph. D., Johns Hopkins, professor of meteorological physics, United States Weather Bureau, says:

These universal slow climatic changes that for thousands of years have been modifying the glaciers and changing the inland seas might very well have led to extensive forest destruction; but that it itself was the effect and the destruction of the trees the cause seems most unlikely.

DESICCATION IN ASIA.

In this connection I would refer to the opinion of Mr. Ellsworth Huntington, B. A. of Beloit and M. A. of Harvord. For four years, 1897–1901, he was the President's assistant and instructor at Euphrates College, Harput, Turkey. He explored the canyon of the Euphrates River in 1901 and was awarded the Gill Memorial by the Royal Geographic Society of London. He was research assistant in the Carnegie Institution, of Washington, and was a member of the Pumpelly expedition to Russian Turkestan in 1903–4. He spent one and one-half years in Turkestan and Persia and a like period in India, China, and Siberia as a member of the Barrett expedition. He has been instructor in geography at Yale since 1907. He explored the Lop basin in Chinese Turkestan, whose length is 1,400 miles and whose maximum width from north to south is 400 miles, embracing an area as large as that portion of the United States east of Lake Michigan and north of Tennessee. Most of the basin is desert. In an article in the Monthly Weather Review for November, 1908, dated at Yale University, November 10 of the same year, he says:

The Lop basin contains abundant evidences of climatic changes, and has been discussed in detail by the writer in "The Pulse of Asia." Throughout the basin the amount of vegetation has greatly decreased in recent times without the intervention of man. On the lower slopes of the Kuenlun Mountains the dissected condition of numerous deposits of loess shows that a cover of grass prevailed at no remote date, but has now disappeared. In the zone of vegetation plants of all kinds show signs of a process of drying up which has been in progress for centuries. Tamarisk bushes stand upon mounds from 5 to 60 feet high, a sure sign of the lowering of the level of ground water; poplar forests which once extended for scores of miles now form wastes of branchless dead trunks like gaunt gray skeletons; and beds of dead reeds cover hundreds of square miles. It has often been asserted that the destruction of forests has been the cause of the diminution of rainfall. In the Lop basin the opposite appears to be the case; the supply of water has diminished, and therefore the forests have died. Rainfall unquestionably controls forestation, but neither in the Lop basin nor in other parts of central and western Asia is there any good evidence that forests have an appreciable effect upon rainfall.

Another important line of evidence is found in the relation of rivers to the desert of Taklamakan and to ruins of ancient dwellings. On the south side of the Lop basin, from Khotan eastward to Lop Nor, the writer examined seventeen streams which are worthy of notice, because of their size or because they support oases. All but four come to an end in the zone of vegetation, where they spread out and disappear either naturally or because used for irrigation. Hence it is impossible to determine whether

or not they have decreased in length. At the lower ends of the other four, old channels are found lined with dead forests, which prove that the streams once extended from 8 to 25 miles farther than is now the case before finally becoming swallowed up in the sand.

FORESTS IN EVIDENCE AFTER STREAMS HAVE DRIED UP.

The fact that dead forests stand long after the streams have receded seems to prove that they are the last to disappear rather than the first, and therefore that their removal did not precede the drought but rather that the forests ceased to exist when the rainfall became deficient. Unmistakable evidence is found of the existence of extensive forests in Arizona and New Mexico, where only the petrified trunks of trees now remain. It can not be said that man removed these forests and brought on the drought.

LOCAL CLIMATIC INFLUENCES OF FORESTS.

One may conclude from the evidence gathered from many sources that summer temperature is slightly less in the forests and in their neighborhood, especially to the leeward, than it is in corresponding cleared sections. Forest temperature is also slightly higher during cold weather than is that of open fields, due presumably to the interference of the trees, even when of the deciduous type, with free ground radiation.

The increase of winter temperature, however, is not equal to the decrease of that of summer, the season during which most vegetation needs all of the heat it can get; and, therefore, it happens that wooded areas may slightly retard the growth of crops in their neighborhood, as is said to be the case in the uplands of Mauritius.

With regard to the effects of forests on rainfall, I quote the following from recent writings of Prof. Cleveland Abbe, who is the senior professor of the Weather Bureau and a member of the National Academy of Science. He says:

> It is a pity that the errors of past centuries should still continue to be disseminated long after scientific research has overthrown them. It is easy to start false theories and to believe them, because they are generally simple and plausible, but long years of work are necessary before we get at the secrets of nature. In this day and generation, the idea that forests either increase or diminish the quantity of rain that falls from the clouds is not worthy to be entertained by rational, intelligent men.

Gauges exposed over forests universally catch more than gauges exposed at the same elevation in the open. Professor Abbe explains this as follows:

> The main trouble consists in the assumption that the water caught and measured in the rain gauge correctly represents the rainfall. Perhaps the most interesting observations bearing directly on this question are those made by Brandis and Blanford in India, where rain gauges were placed both on the ground and above the tree tops at the height of 60 feet in well-watered regions. The high gauges in the forest recorded 4 per cent greater catch than those at the same height in the open fields, and the low gauges on the ground in cleared spaces in the forest gave 2 per cent greater catch than those in open lands. But these figures do not prove that the forest received more rain than the clear areas, although at first sight they would seem to confirm that idea. The fact is that the forest gauges were better sheltered from the wind than the open-ground gauges and this caused them to catch a larger proportion of the rain that fell.
>
> The rain gauge has several sources of error that must be investigated and allowed for, as in all other meteorological apparatus, so that we may not use crude and imperfect data. The effect of the wind in diminishing the catch of the rain gauge has frequently been investigated since the first studies by Mikle in 1819, and the present state of our

knowledge was convincingly summarized * * * in 1887 in an Appendix to Bulletin 7, published by the Forestry Division, United States Department of Agriculture. This Bulletin, edited by B. E. Fernow, "the father of American forestry," recounts the various methods appropriate to the determination of the true amount of precipitation, and its bearing on theories of forest influences.

It appears that in ordinary rainfalls we have a mixture of large and small drops of water descending with various velocities that depend on their size, density, and the resistance of the air. Particles of hail descend even faster than drops of water, but flakes of snow fall more slowly. When the wind strikes the side of a rain gauge the deflected currents move past this obstacle more rapidly, and there is an invisible layer of wind above the open mouth of the gauge, whose horizontal motion is more rapid than that of the wind higher up. Some of the larger falling drops may descend with a rapidity sufficient to penetrate this swiftly moving layer of air, but the slower ones will be carried over to leeward and many will miss the gauge. The resulting loss of rain will depend upon both the horizontal velocity of the wind and the vertical velocity of descent of the rain.

The fact that the deficit increases with the velocity of the wind (which is less over the forest) has also been proven in a different way, viz, by shielding the gauge from the wind, when the deficit becomes greatly reduced in value. Professors Henry, Nipher, Boernstein, Hellmann, all of them eminent investigators, agree in this conclusion.

Of two gauges exposed at the same elevation above the ground, one over the open fields and the other over a forest, just above the tops of the trees, the one over the forest will catch considerably more rain, because the friction of the trees reduces the velocity of the wind and it does not rush across the open end of the gauge with the same speed that it does across the gauge over the open fields.

The influence of a forest upon the rainfall is therefore only apparent; it may increase or diminish the *catch of the gauge*, but not the quantity of *rain falling from the cloud.*

Professor Abbe further says:

If gauges are raised up year by year, the deficit increases; if gauges in open fields become surrounded by growing trees or higher buildings, the deficit decreases. The *climate* has not changed, but the *errors* of the *record* have done so. Those who wish to restore the good old times before the forests were cut down, when rain and snow came plentifully and regularly, have only to lower and shelter their rain gauges and snow gauges and, *presto*, the climate has changed to correspond.

When rain is falling on a forested region, about 25 per cent is temporarily held far above the ground on the leaves and branches of the trees. In this minutely divided condition, exposed to the action of the wind, the drops evaporate freely, so that the forest atmosphere becomes saturated and decidedly less moisture reaches the ground to be absorbed in the forest humus than on an equal volume of soil outside the forest. A special climate is therefore maintained within a forested area. The temperature is lowered and the relative humidity is increased, but there is no evidence that this local forest climate extends outside the forest or affects exterior conditions to any important extent. Of course, the climate under a tree or a tent or within a house differs from that outside, but these are local matters quite foreign to the broad question, Do forests affect climate?

The climate within a house is not the climate of the whole city, nor is the climate of a ravine that of the surrounding fields. One thermometer or rain gauge in the open air does not give the climate of a State or watershed. The various and restricted uses of the word "climate" have led to our confusion.

LOCAL TEMPERATURE DIFFERENCES DUE TO CHARACTER OF SOIL COVERING.

As the result of investigations begun in Wisconsin by the author over fifteen years ago and continued during the past three or four years by Prof. Henry J. Cox, of the Weather Bureau, we have found that surprising results are obtained on two surfaces of precisely the same level on adjacent fields, one of them covered with thick vegetation and the other covered 2 inches deep with sand. We have

noted differences in temperature frequently of 7° to 9° in the air immediately adjacent to the surface or within a stratum 3 inches deep, this difference being so great that one area would receive a heavy deposit of frost and the other (sanded section) be entirely free from such frigid temperatures; and the difference in temperature between a thermometer exposed in the heart of a city and one in the open field but a few miles away was found to be marked. As an illustration: A thermometer in a shelter at La Crosse, Wis., registered 50° minimum temperature on a certain morning, while a thermometer in the cranberry marshes 50 miles away fell to freezing; but these were all local irregularities. The difference in temperature between the air over thick vegetation and that over the sanded surface disappeared within a height of 3 feet, and it is probable that the temperature over La Crosse and over the cranberry marshes was the same at an altitude of 200 feet.

CHANGING THE LOCAL CLIMATE BY ARTIFICIAL CONDITIONS.

The covering of tobacco plants with thin cheese cloth results in establishing a local climate which will continue so long as the cheese cloth remains in position. The extremes of temperature, both heat and cold, are reduced, and the resulting climatic change produces a marked effect upon all vegetation grown under the artificial conditions. The erection of a tent, of a barn, of a dwelling house, of a village, or the growth of a great city, respectively, influence the local climate in proportion to the area that is covered, modified by the character of the material used in these constructions. Likewise the vegetable covering of the earth may have a local appreciable effect. The flooding of an area, the cutting away of forests, erosion, and sanding may have either minute or appreciable effects upon local climates in proportion to the magnitude of the areas affected, *but this does not mean that there is any great difference in the climatic effect between a forest covering and one of bushes, of grass, or of growing crops; and it does not signify that there is sufficient change in the thermal conditions, due to the activities of man, as to make an appreciable difference in the temperature at an altitude of one or two hundred feet, or to affect the general climatic conditions, or to cause storms to be more frequent than formerly or of greater severity, or to increase the amount of precipitation.*

A PLEA FOR TOLERANCE OF OPINION.

But this discussion should not be approached in an intolerant spirit. We have accurate records of climate from only a few isolated places in this country that extend back for a period of as much as one hundred years, and the Government's extensive records only cover a period of forty years. I would warn against hasty conclusions; against accepting as final the deductions of several investigators who have recently publicly discussed the flood records of the Weather Bureau. They find a most alarming increase in the floods of the Ohio Valley and other places, for which I find no justification. Let logic, reason, and investigation have time to operate, for any man may be honestly mistaken and draw general conclusions from inconsequential details or deceive himself by the improper grouping of data.

RECORDS OF PRECIPITATION SHOW NO MATERIAL CHANGE.

The records of precipitation of the United States Weather Bureau do not show that there has been any appreciable permanent decrease in the rainfall of any section of the United States. There are undoubtedly periods covering a number of years of continued deficiency in precipitation for certain districts, but at the same time other districts may show a corresponding increase. One of the best and longest records of precipitation of the eastern part of the country is that made at New Bedford, Mass., by Mr. Samuel Rodman and his son, covering the period from 1814 to within a year or so ago, a period of about ninety-five years. The following table shows the annual amount of precipitation during each year of the above-named period, from which one can see for himself the variations in the amounts from year to year, by the ten-year period, or make other comparison:

TABLE 1.—*Annual precipitation at New Bedford, Mass., for the period, 1814 to 1908.*

Year.	Amount.	Year.	Amount.	Year.	Amount.	Year.	Amount.	Year.	Amount.
1814	43.08	1833	42.62	1852	46.14	1871	49.60	1890	61.69
1815	40.78	1834	45.12	1853	39.47	1872	47.66	1891	47.83
1816	44.13	1835	47.21	1854	53.82	1873	51.70	1892	42.83
1817	43.33	1836	42.83	1855	41.00	1874	49.34	1893	50.27
1818	40.77	1837	39.07	1856	37.09	1875	48.33	1894	45.89
1819	39.66	1838	38.28	1857	43.30	1876	42.18	1895	41.63
1820	41.32	1839	44.38	1858	44.03	1877	47.04	1896	47.73
1821	45.64	1840	45.59	1859	51.43	1878	50.56	1897	50.96
1822	41.78	1841	50.60	1860	39.73	1879	42.31	1898	62.60
1823	59.89	1842	39.06	1861	46.46	1880	40.07	1899	44.34
1824	47.34	1843	50.67	1862	43.32	1881	39.10	1900	44.99
1825	38.09	1844	40.73	1863	45.10	1882	41.38	1901	51.84
1826	54.77	1845	48.06	1864	40.96	1883	43.51	1902	45.42
1827	62.90	1846	34.51	1865	46.01	1884	54.99	1903	47.49
1828	39.04	1847	45.91	1866	40.30	1885	36.81	1904	50.08
1829	65.41	1848	40.74	1867	47.11	1886	49.85	1905	41.30
1830	64.66	1849	36.42	1868	56.32	1887	51.77	[a] 1906	43.09
1831	61.18	1850	62.67	1869	49.94	1888	55.07	1907	42.32
1832	49.31	1851	51.61	1870	47.16	1889	52.71	1908	38.61

[a] The record for New Bedford ends with the year 1906; annual amounts for 1907 and 1908 are for Fall River. Mass.

The average fall for ten-year periods from 1814 to 1908, inclusive, indicates that while the rainfall during the past few years has been considerably less than the average, it has not been less than has occurred in numerous previous years—notably from 1814 to 1819, from 1833 to 1839, and from 1860 to 1866. Further investigation shows that for the first fifty years of the period the average annual rainfall at that point was about 46 inches, while during the last forty-five years the annual fall has increased to more than 47 inches. *This indicates that instead of a diminishing rainfall we have the evidence that, if there is any variation at all in the precipitation, it is a slight increase for this region.*

Figure 1 graphically shows the average fall for ten-year periods, namely, from 1814 to 1908, inclusive.

We will now move our inquiry to a part of the Middle West where there has been no deforestation. Here there has been a growth of planted hedge rows, of trees along highways and fence lines and about places of habitation, and the virgin soil has been broken and made more permeable to the rainfall.

New Bedford, Mass.

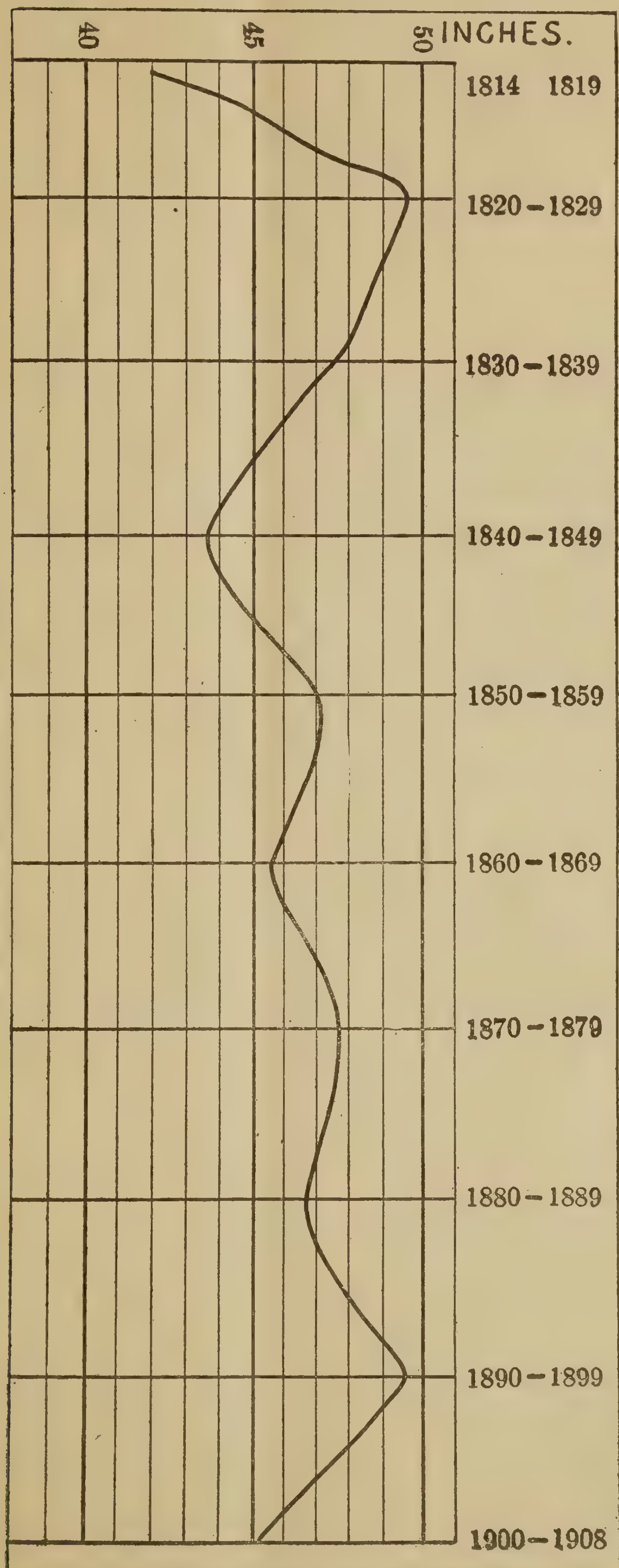

Fig. 1. Average rainfall in ten-year periods.

In Kansas during the last fifty years records of rainfall have been made only in the eastern part of the State. In the western part of the State a single record has been made, viz, at Dodge City, extending back to 1875. Likewise in Nebraska, the record for North Platte is the only one that extends back to the early seventies. The mean annual rainfall at Dodge, Kans., for the entire period of observation is 20.8 inches, and at North Platte, Nebr., 18.7 inches.

Considering the record for the last thirty years only, since it is convenient to subdivide that number into periods of equal length, the mean becomes for Dodge, 21.3 inches, and for North Platte, 19 inches. I have also had computed the average rainfall for three additional stations in Kansas, three in Nebraska, and one each in Iowa and Missouri for the last thirty years, to see whether the conclusions reached from a consideration of the Dodge and North Platte data are of local or general application. The averages in periods of ten years each appear in the following table, from which it may be clearly seen that the first and the last ten years were periods of fairly abundant rainfall and that the middle ten years was a period of deficient rainfall. It will be further seen, and this is the important point in the discussion, that there is practically no difference between the rainfall of the first ten years and the last ten years. Three of the ten stations show that the last ten-year period had a slightly greater rainfall than the first, but the difference is so small that it is really immaterial. The remaining stations show a slightly less rainfall in the last ten years than in the first. This table shows, therefore, that the rainfall has neither increased nor diminished by amounts worthy of consideration.

The heavy rains of 1906, and also the year previous, were common to all that vast stretch of territory west of the ninety-fifth meridian. It was not a local phenomenon centered in western Kansas and western Nebraska, since equally heavy rains fell in Colorado, Utah, western Texas, Oklahoma, New Mexico, Arizona, Nevada, and central and southern California. The explanation of the heavy rains can not be attributed to local conditions of soil and moisture, since, as has just been stated, the heavy rains were common to the arid and mountain regions of the Southwest where very little agriculture is practiced.

Mean rainfall at the stations named.

Stations and periods of observation.	For the full period of observation.	For the thirty years, 1877-1906, in periods of ten years.			
		First.	Second.	Third.	Mean.
	Inches.	*Inches.*	*Inches.*	*Inches.*	*Inches.*
Dodge, Kans., 1875-1906	20.8	22.8	18.4	22.7	21.3
North Platte, Nebr., 1875-1906	18.7	20.1	17.2	19.8	19.0
Independence, Kans., 1872-1906	37.1	39.1	35.5	38.1	37.6
Genoa, Nebr., 1875-1906	28.2	26.3	26.4	31.3	28.0
Manhattan, Kans., 1858-1906	30.6	33.4	29.2	31.9	31.5
Lawrence, Kans., 1868-1906	36.4	35.1	39.2	36.7	37.0
Omaha, Nebr., 1871-1906	30.7	37.6	25.6	27.9	30.4
Minden, Nebr., 1878-1906	31.5	36.1	29.2	29.8	31.7
Oregon, Mo., 1866-1906	35.6	37.1	32.3	39.5	36.3
Keokuk, Iowa, 1872-1906	35.0	35.4	31.4	35.1	34.3

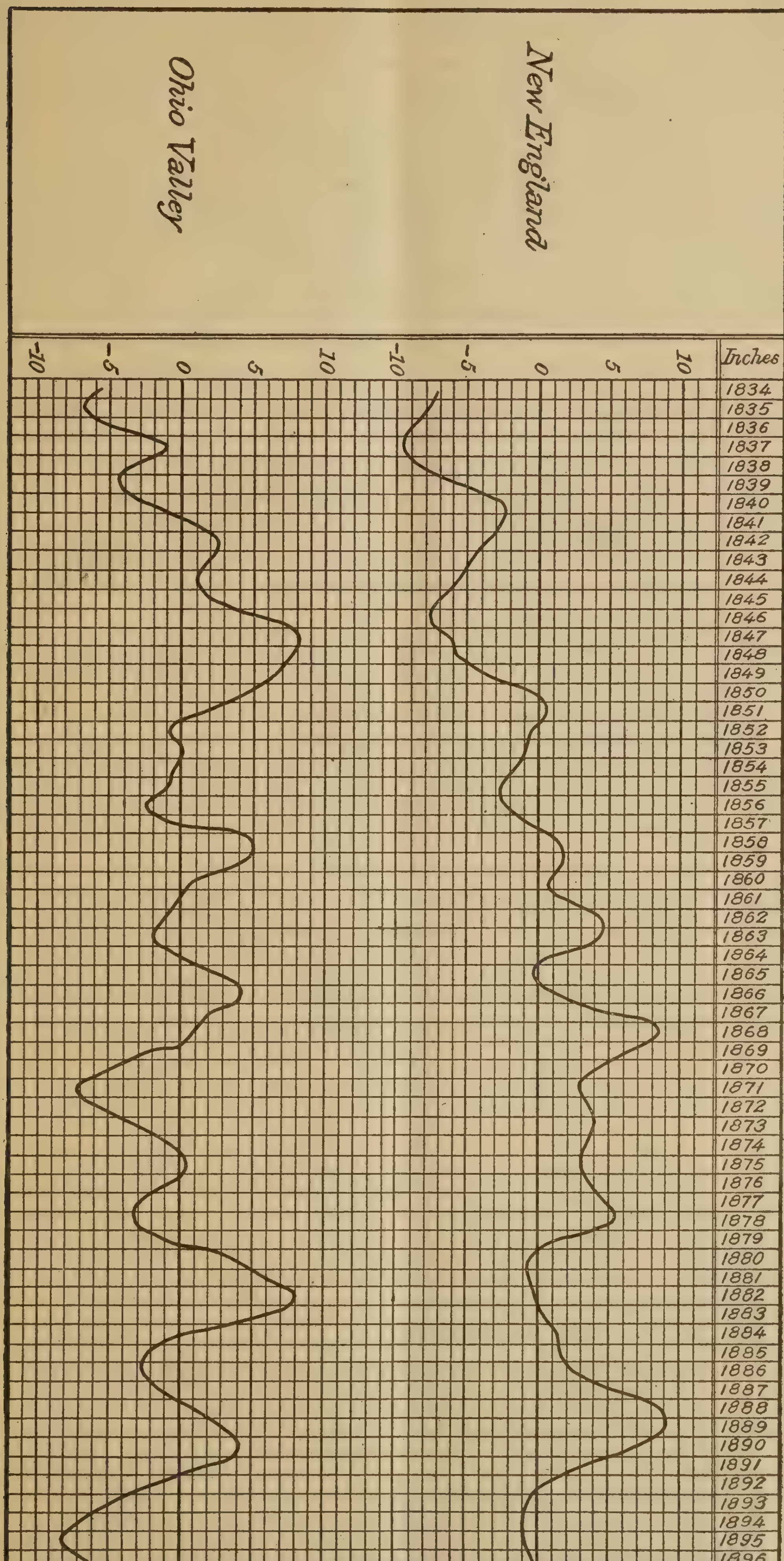

Fig. 2. Progressive Averages of Precipitation, 1834–1896.

The annual fluctuation in precipitation for two different parts of the United States, viz, New England and the Ohio Valley, is graphically shown in figure 2. The New England curve was constructed from the data for Boston, New Bedford, and Providence, at which points fairly accurate rainfall measurements have been made dating back to 1836. The Ohio Valley curve is based upon rainfall measurements made at Marietta, Portsmouth, and Cincinnati.

The heavy horizontal lines in the diagram represent the normal precipitation. The amount that the actual fall of any year exceeded or fell short of the normal may be found by noting the intersections of the curved lines with the smaller horizontal lines, whose values are given in inches on the left margin. If periods of heavy and light rainfall alternated regularly, the lines of departure from the normal (the curved line) would rise and fall in a series of bends or inflections precisely as the temperature rises and falls with the alternation of day and night. Reference to the diagram itself will best show how closely the rainfall of the two regions approaches any sort of periodicity. The Ohio Valley curve is more symmetrical than that of New England, and there appears to be a rough periodicity of about nine years in it. Thus there were periods of heavy rainfall about 1837, 1847, 1858, 1866, 1875, 1882, and 1890, and of drought in 1839, 1856, 1863, 1871, 1878, 1886, and 1895.

A comparison of the two curves illustrates the fact elsewhere referred to that the rainfall over a region so large as the United States is not by any means uniform in its distribution. Thus the period of relatively light rainfall in New England during 1880–1883 was one of heavy rainfall in the Ohio Valley and elsewhere in the great interior valleys. Likewise in 1878 there was heavy rainfall in New England and light rainfall in the Ohio Valley.

In New England, where deforestation began early in our history and has been extensive, the mean of the fluctuations in the rain curve is a steady rise since 1836 up to a few years ago, and in the Ohio Valley, where the forest area has been greatly diminished, there is no decrease of rainfall shown by the average of the fluctuations of the curve. These facts are important and can not be successfully disputed.

GOVERNMENT RECORDS VERSUS RECOLLECTIONS OF OLDEST INHABITANTS.

It is the duty of the United States Weather Bureau to publish information with regard to climatic conditions; and in this connection I would call particular attention to the fact that the government records are in a class separate and distinct from the recollections of the oldest inhabitants, which are entirely untrustworthy, no matter how truthful the persons intend to be. These recollections do not justify the claim that the forests have increased precipitation, for it is almost the universal opinion of the maturer man that the climate is milder and that the snows are less deep than when he was a boy. He remembers the long tramp to the little red schoolhouse in snow knee deep, but he fails to take into consideration the fact that a snow knee deep to a boy of nine years of age is no inconvenience to a man of six feet two. Human recollection can only recall from the dim past unusual storms—conditions that were abnormal, and these abnormalties are what the man of fifty or sixty years to-day believes to

have been the average when he was young. In other words, the individual recollection should be given little weight in determining a matter that requires careful calculation and the preservation of accurate daily records before anything like safe conclusions can be reached.

THE EFFECT OF FORESTS ON FLOODS.

I have always held to the opinion that the cutting away of forests has had little or no appreciable effect on the amount of precipitation or on the general temperature. But until recent years I did believe that deforestation had an important and beneficial effect on the conservation; that is, on the economical use of the rainfall, and that forests restricted the run-off. But study and investigation have caused me to modify my views.

Professor Abbe says:

> The cultivated soil outside the forest, when plowed and broken open down to a depth of 8 inches, acts as a sponge to retain water quite as well as does the ordinary humus of a forest, especially when we consider that under a forest less rain actually enters the humus. In fact such measurements as have been made show that the amount of water that is eventually given up from the forest humus varies but little from that given up in the course of time by the unforested, cultivated soil. The total run-off from the two regions does not eventually differ greatly, but it does differ in the speed. However, it may be neither the amount nor the speed of run-off from the soil that determines the occurrence of river floods. We must distinguish between the soil run-off and the river run-off. When water has once entered the river channel its movements are determined wholly by the force of gravity, the curvature, the section, and the slope of the channel. Floods may occur in every small tributary and yet these waters may so enter the main channel as to produce only a gentle rise throughout its whole length. At other times the smaller elementary floods may conspire and produce a specially disastrous flood in the main channel. Therefore the occurrence of disastrous floods does not depend on rainfall alone or wholly on soil run-off, but equally and principally on the relative times at which floods occur in the individual tributaries, and the time required by them all to reach and combine at any given point in the main channel.

This is a tangled problem, since the result must depend upon the slope of the ground; the nature and condition of the soil; the nature of the forest, whether deciduous or evergreen; the nature of the general climate of the place, whether it has cold, snowy winters or rainy ones, and whether the spring merges gradually or abruptly into summer; upon the use or treatment of the cleared surface; and probably upon other conditions.

The foresters are generally in accord in the belief that the forests exercise a marked restraining influence on floods and a conserving influence on precipitation, even if they do not actually increase, by an appreciable amount, the rainfall. On the other side, army and civilian engineers and meteorologists generally believe that the broken, cultivated, permeable soil, which is covered for a greater portion of each year with millions of the rootlets of growing grasses and cereals, is equally as good a conserver of the rainfall as the forest area itself, even though the latter has the advantage of the deep boring of large roots into the substratum; that the evergreen forests prevent the drifting of the snow and at the same time their heavy foliage protects the snow from the sun and permits a slow melting, which is all absorbed by the forest cover until it is saturated, and then with further heat the water breaks out in a flood; that the function of deciduous forest trees is to catch the falling snow, distribute it equally over the surface, and thus facilitate more rapid melting by causing the snow to present to the warm air a greater melting surface than it does in the

open, where wind drifts it into banks in the lee of opposing objects and stores it in depressions and ravines, so that it may remain for a considerable time after the evenly distributed blanket has disappeared from the forests.

It has been shown by Chittenden that in Yellowstone Park and similar mountain regions the forests protect the snow from drifting, melting, and evaporating, while in the open there is much drifting and an early clearing up of those places well exposed to wind and to sunshine; therefore, when warm weather and its rain come on abruptly, and come to stay for the summer, as they do in those regions, the melting of the snow in the forests, because of the greater area exposed, the surface being uniformly covered, is far more rapid than it is in the open where it is badly drifted, and leads to higher freshets and less enduring run-offs. *On the whole, it is probable that forests have little to do with the height of floods in main tributaries and principal streams, since they occur only as the result of extensive and heavy rains, after the ground is everywhere saturated, or when heavy warm rains come on the top of deep snows.*

RUN-OFF AND ABSORPTION.

Concerning the surface run-off, it appears to be generally held that when the rainfall is small, the dead leaves, the moss, the tangle of undergrowth, and the like, in the forests may modify or entirely prevent flow, and may slightly intensify low-water conditions of summer, while on the cleared surfaces, except that of freshly-cultivated fields, this is not so markedly the case. When the rains are heavy and continued, there is surface flow in the forests as well as in the open, and the two do not materially differ, for it can be shown that the run-off from a smooth surface and from one covered with sticks, dense grasses, or forest, are equal after the rough surface becomes saturated, and it is long after *all surfaces* have become saturated that flood conditions can occur.

Because of their open, porous condition sandy soils and freshly plowed fields are the best absorbers, and in general forest ground is thought to be more penetrable to moisture than is that of the cleared fields, except when the latter are freshly broken, but the greater part of the cleared land is either broken and cultivated several times during the year or else it is occupied by vegetation that exercises either partly or wholly as great a conserving influence as the forest.

All of these problems could be definitely settled beyond the possibility of argument if we had accurate river gaugings from day to day and year to year, together with a full knowledge of the rainfall and of the proportion of the wooded to cleared areas, data that unfortunately we do not have. We must, therefore, reason empirically from the best information at hand, and this insufficiency of data renders less positive the conclusions of all investigators, no matter which side of the question they may be on.

EFFECT OF FORESTS ON FLOODS IN FRANCE.

An important contribution to this discussion was made in 1873 by Capt. Charles J. Allen, of the Engineer Corps, U. S. Army, in the translation that he made of extracts from the work of M. F. Vallès, which treats of the influence of forests on floods and inundations.

This translation contains quotations from the works of M. Belgrand and other French engineers, who had made the hydrology of the basin of the Seine a special study.[a] Among other things M. Belgrand says:

This country comprises all or part of 21 Departments, as follows: Aisne, Ardennes, Aube, Cote d'Or, Eure, Eure-et-Loire, Loiret, Marne, Haute-Marne, Nievre, Nord, Oise, Pas-de-Calais, Seine, Seine-Inferieure, Seine-et-Marne, Somme, Vosges, and Yonne, and comprises an area of about 107,000 square kilometers, nearly equal to the fifth part of the area of country comprising the 86 Departments.

The most irregular streams, those most subject to rapid rises, are found especially in the Departments of the Yonne, Nievre, and Cote d'Or, and to a less extent in those of the Aube, Haute-Marne, and Aisne. This region is very woody, more so, perhaps, than the rest of France. The most remarkable Departments in regard to the regularity of the water courses which rise within them are the Eure, Eure-et-Loire, Nord, Oise, Pas-de-Calais, Seine-Inferieure, Somme, the chalky parts of the Aube and of the Marne, and those portions of the Seine-et-Oise and Loiret in which the limestones of La Beauce abound. The majority of the streams in these countries are subject to slight rises of short duration, their stage of water varying but little. This group of Departments is perhaps one of the most sparsely wooded in France, because the Eure, Eure-et-Loire, Nord, Oise, Pas-de-Calais, Seine-Inferieure, and the Somme have only about one-tenth of their surface wooded, and the plateaus of La Beauce and the chalky plains of Champagne are, if we except some recent plantations of pine, completely bare of trees.

In order to test the question as to the effect of forests in regulating the flow of water M. Belgrand had daily measurements made from November, 1850, to May, 1853, of the discharges of the Cousin and of the Grenetierre, which is one of its affluents. Both of these basins are of granite formation, impermeable and otherwise alike, but the first is only about one-third wooded, while the second is entirely covered with trees. Notwithstanding this great difference as regards the extent of forests in each, the results have been the same in both, as is shown by the following account:

"The regimen of each is identically the same, although their valleys are unequally wooded. Their waters rise and fall at the same rate, whether in rainy weather or in dry, in winter or in summer; their low winter regimen is more abundant than that of summer.

"A heavy rain in winter produces in both a sudden flood of greater or less height, but of very short duration, followed by a long stage of tolerably high water; the sudden and high freshets take place in each at the same time."

The different details concerning the flow of water are, then, exactly the same in the two basins, and yet one is entirely covered with forests, while in the other two-thirds is bare of trees. M. Belgrand has made a number of more detailed observations yet, which show, further, that it is not upon forests but upon cultivated ground that the greatest regularity in flowage is observed. * * *

In Vallès's paper he quotes from a report on the basin of the Eure made by M. St. Clair, engineer in chief, showing the beneficial effects of cleared and cultivated lands in diminishing by absorption the amount of surface water, as follows:

All the valleys, even those of least extent, are cut up by ravines which were often formerly the beds of torrents. Within the last twelve years the condition has changed; they are now almost always dry. The cause of this great change, the progress of agriculture, is generally recognized in the country. The soil has been cultivated more and rendered more permeable; the farmers, reaping more advantages from the culture of the ground, and fully aware of the utility of improving it, have, by means of ditches, hedges, and endikements properly located, controlled the flow of water everywhere, preventing erosion, causing fertilizing deposits of sediment, and relieving the surface of the ground from the asperities which interfered with cultivation. The waters, retarded thus in their flow, have settled in great part through the ground and disappeared before reaching the ravines.

These agricultural improvements, in a country where land susceptible of cultivation, amounts to sixty-one one-hundredths of the area of the country, have, then, reduced the surface flowage and increased the absorption.

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[a] Annales des Ponts et Chaussees, annee 1852, premier semestre, p. 102.

They have rendered less frequent and formidable the freshets, which, in the basin of the Eure, are to be attributed to an excess of surface water rather than to any supply from springs, which latter is almost always invariable.

The effect upon springs of cutting down forests can now be easily eliminated. We will divide them into two classes, viz, superficial and subterranean.

The first issue from the points of the surface very near to the strata in which the waters which produce them collect. The second, on the contrary, are found very far below these strata, and the water, in order to find an outlet, traverses frequently long distances underground.

The first, generally small, pertain indifferently to absorbent or nonabsorbent ground; but the second, occasionally very powerful, pertain essentially and almost exclusively to permeable soils.

Now, it is indisputable that the continual humidity of the soil of forests is favorable to the first and ought to maintain in their feeble flow considerable regularity. It is, then, very likely that the clearing away of forests and exposing the earth to alternations of drought and moisture would alter the regimen of these springs; that these would be more abundant in time of rain; that they would decrease in summer and possibly be dry for several months in the year. This explains the disappearance of certain springs after the cutting down of forests.

As regards the second group, which are plentifully supplied by infiltration through the permeable soils, it is different.

From the different manner in which, as regards absorption, wooded and cultivated soils act, we see that in the first this faculty is in great part destroyed, while in the second it is increased. To remove standing timber from permeable soils is to restore to them the facility of transmitting the waters which the forest vegetation, whether by the spreading of its roots, by the fall of leaves, or by the compactness of the soil, had taken from them, and it results, consequently, in a more abundant supply of water to the subterranean springs.

Thus, it is worthy of remark that the most abundant of all of them, especially in seasons of low water, are located beneath the vast ledges of limestone which are almost entirely denuded; for instance, those of Cahors and Louysse, in the department du Lot, and the famous fountain of Vaucluse, of which mention has already been made.

M. Belgrand further says:

Now these basins, so remarkably alike, we have; they are those of the Seine in the seventeenth, eighteenth, and nineteenth centuries. Everything in these is alike excepting the extent of the forests, which has steadily decreased, so that if we were in possession of adequate information of some exact measurements of the greatest inundations during the time specified, we could easily test the correctness of our theories.

In fact, observations of this nature have been made; they go back to 1615, about the time when French industry began to develop, and when, consequently, the felling of timber to a great extent commenced.

This places at our disposal an interval of five half centuries.

In a memoir published in 1814 by the engineer Egault, these observations were compiled, discussed, and arranged with reference to the heights of the most marked inundations. We add to the results collated by them those which have been obtained since his time and give them in the following table:

Dates of the inundations.	Height at the bridge of La Tournelle.	Mean per half century.
	Feet.	*Feet.*
July 11, 1615	29.99	27.53
January, 1649	25.10	
January, 1651	25.59	26.36
March 1, 1658	28.87	
March, 1690	24.61	
March, 1711	24.77	25.34
December 25, 1740	25.92	
January, 1751	21.98	22.42
November 14, 1764	22.97	
March 4, 1784	21.85	
February 4, 1799	22.87	
January 3, 1802	24.44	21.22
March 3, 1807	21.85	
May, 1836	18.66	
February, 1850	19.91	

The deductions from this table are striking. The continued decrease of the floods for each half century is remarkable. The waters attained a mean height of 27.53 feet in the first half of the seventeenth century; they only attained a mean of 21.22 feet in the present. According to this, we have experienced an amelioration of nearly 6.56 feet, and yet the trees have been steadily and unceasingly cut down, and the forests transformed into cultivated farms.

What would we gain, then, to-day, I ask, in rewooding our field? It would be but an unfortunate attempt to restore the old order of things, when the floods of the Seine rose to 29.53 feet above the low stage.

In connection with the conclusions reached in this report, as well as with regard to those reached by the foresters and others who differ from my views, I would emphasize the fact that none of us have flood data extending over any great period of time, but in Europe we fortunately have some long-period observations. The preceding pages show the result of observations made by competent engineers during two and one-half centuries in the basin of the Seine, and show that there has been a gradual and constant decrease in the height of floods with the diminution of forests.

In Germany another long-period record is presented. Mr. Ernest Lauder, chief of the hydrographic bureau of the Austrian Government, recently made an exhaustive investigation of the records of the Danube, the great river of central Europe. He prepared an exhaustive report on the destructive floods in the Danube that occurred in 1897 and 1899, and in this report traces the history of the floods of the Danube for eight hundred years, taking into account 125 different floods. His conclusions are that progressive deforestation of the country has had no effect in increasing the frequency of floods or in augmenting their height. Among other things he showed that the flood of 1899, which was a summer flood, was severest where it came from the heavily wooded districts.

Much has been written about the barren condition of the valley of the Jordan, in the Holy Land, and it is pointed out that great cities and teeming populations once covered the regions now barren; but this does not prove that if there has been a decrease in the rainfall it is due to deforestation, for everywhere in this region are evidences of extensive irrigation that was practised at the time this region was thickly populated. The date palm, the vine, and the fig tree will grow there as luxuriantly to-day as in the old Biblical days, if artificial irrigation is used, as was formerly done. It is not believed that the cutting of the cedars of Lebanon has had anything to do with the dryness of the adjacent regions.

At the tenth International Congress of Irrigation, held at Milan in 1905, papers were presented by representatives from France, Germany, Italy, Austria, and Russia, in which the writers heartily favored the protection of the forests and their cultivation. But these writers were unanimous in the opinion that forests exercise little influence upon either the high water or the low water of rivers.

In this connection I will quote from Col. H. M. Chittenden, M. Am. Soc. C. E., volume 34, page 944, Proceedings of the Society of Civil Engineers, as follows:

The constantly reiterated statement that floods are increasing in frequency and intensity, as compared with former times, has nothing to support it. There are, it is true, periods when floods are more frequent than at others, and hasty conclusions are always drawn at such times; but, taking the records year after year for considerable periods, no change worth considering is discoverable. The explanation of these periods of high water, like the one now prevailing, must, of course, be sought in pre-

cipitation. That is where floods come from, and it is very strange that those who are looking so eagerly for a cause of these floods jump at an indirect cause and leave the direct one entirely untouched. In the records of precipitation, wherever they exist, will be found a full and complete explanation of every one of the floods that have seemed unusually frequent and severe in recent years.

THE SOURCE OF FLOOD WATERS IN THE UNITED STATES.

Before one can get a comprehensive idea of the magnitude of the problem involved in the creation of the floods of the United States, it will be necessary for him to first study chart A, which gives a typical illustration of the cyclonic storms that frequently form on the Rocky Mountain Plateau, either on its northern, central, or southern portions. Under the influence of gravity air flows from regions where the pressure is great toward the regions where it is less. In the case illustrated by this chart the atmosphere, as indicated by the direction in which the arrows point, is flowing from the region marked "high," which is central over the Carolinas, toward the region where the pressure is low, which is central over Montana, and the vaporous atmosphere that rises from the Gulf of Mexico and the adjacent ocean is carried far into the interior of the continent. Conditions similar to these occur many times each month, and as a result the eastern and central portions of the United States are bathed in a succession of rains which, as shown by chart B, gradually thin out and largely disappear on the eastward edge of the Rocky Mountain Plateau, because the currents of air from the Gulf of Mexico do not reach farther inland.

STATEMENT BY MR. BAILEY WILLIS.

In the May issue, 1909, of the magazine entitled "Conservation," page 262, Mr. Bailey Willis makes the statement:

> The moisture which falls upon North America in the form of rain and snow comes chiefly from the Pacific Ocean. A smaller proportion, rising from the Gulf of Mexico and the West Indian seas, falls upon the eastern United States.

It is true that chart B, giving the normal annual precipitation indicates that the Pacific Ocean furnishes precipitation that is heavy along the immediate coast, but that it is the principal source, as Mr Willis says, of the moisture that falls upon the North American Continent, is not borne out by the facts exhibited by the precipitation chart herein produced and by the inflowing currents of air that are shown on chart A.

The range of mountains on the Pacific coast intercepts the inflow of the vaporous atmosphere, which is comparatively shallow, and precipitates its aqueous vapor on the windward side of the range, and mainly on the north half of the windward side, because storms seldom enter from the southern half. To be sure, some of the scant precipitation that falls on the plateau does drift over the tops of these mountains, but the amount is small. Certain it is that the Pacific Ocean has little influence on the precipitation of the eastern half of the United States, which fact is well understood by meteorologists; and I believe that most of them will join me in the belief that the only way that man could materially affect the rainfall of the eastern half of the United States would be to erect a mountain barrier

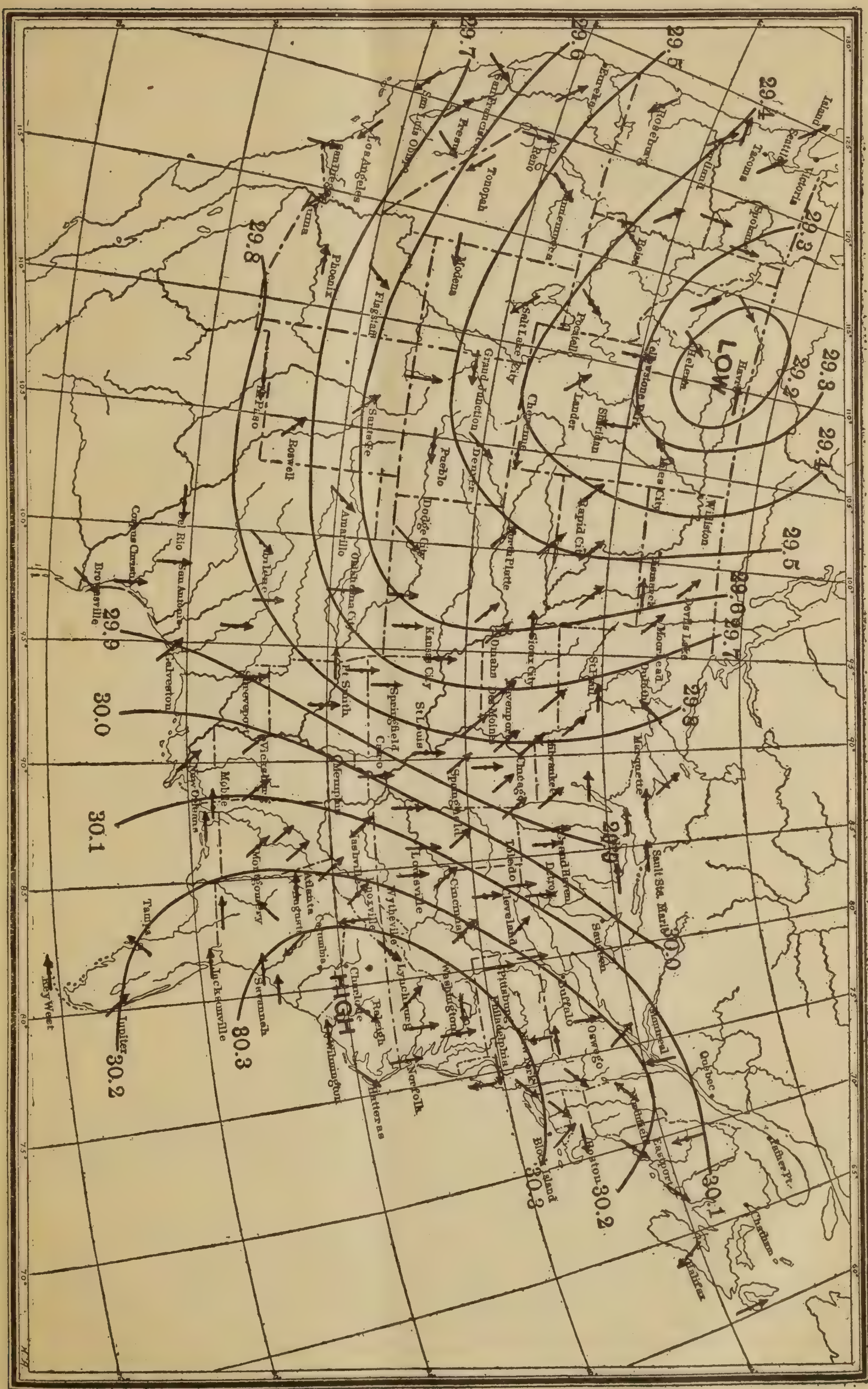

CHART A.—Arrows fly with the wind and show how the vaporous atmosphere of the Gulf of Mexico and the South Atlantic Ocean is drawn inland.

10,000 feet high skirting the Gulf and South Atlantic coasts. Of course this is impossible, but if nature had erected it there would be no question about floods in the Ohio and the Mississippi rivers and their tributaries, for there would be neither rivers nor tributaries; just as on the Pacific coast, the rain would fall on the ocean side of the mountains, and the world's greatest granary would be a barren waste.

Prof. Frank H. Bigelow, on page 17 of A Manual for Observers in Climatology and Evaporation, says:

> All this distribution of the general circulating currents, and the consequent precipitation, would occur whether there were forests or not growing on the land masses. It may be proper to say that the forests follow the precipitation and do not precede it.

There can be no question but that the action of the sun on the waters of the Gulf of Mexico and the adjacent ocean heavily charge the air with water vapor, and that this vaporous atmosphere is carried inland by the circulation of the air in such storms as are described in a preceding paragraph and illustrated on chart A, and that the effect is shown on chart B in the form of heavy precipitation in the region of the Gulf, which gradually shades away toward the Rocky Mountains.

It is therefore apparent that the precipitation that causes floods in the eastern half of the United States is from the aqueous vapor that is raised up from the vast waters to the south and southeast of our continent, and that *the supply is inexhaustible. Our rainfall, then, is the result of such fundamentally great causes as not to be appreciably affected by the planting or cutting away of forests, or by any of the operations of man in changing the character of the surface covering of the continent,* although to statistically and positively settle the question beyond the possibility of argument it would be necessary to have scientific data of temperature, rainfall, and the height of rivers, beginning at the first settlement of the continent and continuing through to the present time. Such records, of course, are not in existence. But the fundamental fact that the precipitation of the United States is due to the great hemispherical circulation of the air, and to the relation of the great bodies of water to land, and the direction of the vaporous-bearing currents, and the trend of mountain systems is something that can be positively shown.

Mr. Willis further says, in the same issue of Conservation, page 265, that:

> The mountains are wet because they are high, and they are heavily forested because they are wet. But there is also a reciprocal action of the forests on the wetness, for the radiation from the dark-green expanse is comparatively uniform and promotes frequent and steady rains. Were the mountains bare they would, like the bared sierras of Spain, receive occasional but violent downpours and send down excessive and disastrous floods, even more disastrous than now. * * * For in so far as we clothe the surface with green crops we lower the temperature of the rising air and favor precipitation on the verdure-covered plain.

It would be difficult to either confirm or disprove this statement of Mr. Willis. Certain it is that the rain is precipitated largely from air masses that exist at a considerable distance from the surface of the earth, and that the influence that Mr. Willis describes is in a thin stratum of air close to the earth. Rarely is this stratum saturated, even during the fall of rain. If, then, the processes that he describes do not bring the air to the saturation point, and if the

CHART B.—Annual precipitation.

precipitation occurs in the regions above those affected by these local surface conditions, I am unable to see how the rain can be either increased or decreased in its amount. Certain it is that most of the leading meteorologists of the world are of the opinion that the rainfall on continents is caused by the fundamentally great operations of nature as described above.

EROSION.

Another effect of deforestation, that of erosion, is of importance, but of unequal importance in different sections. In level countries it makes but little difference in this particular whether the ground is waste, cultivated, or densely forested, while in hilly or mountainous sections the result is different. When the soil becomes well sodded with grass, erosion is little worse in fields than in the woods, but usually the fields are cultivated from time to time, and occasions come when the best of care and cultivation can not prevent the formation of bad gullies that injure both the gullied fields and those of the lower grounds that are overflowed.

Of course, though, a field with an occasional wash yields more food material than the same area covered by a forest of any kind, so that only in exceptional cases—those in which erosion would probably be unavoidable and ruinous—is this a sufficient argument against clearing away the woods and the planting of crops in their stead, *for the time is come when we should not only increase the yield per acre by wise rotation of crops on cultivated ground, but clear up and seed to wheat, corn, grass, and fruits millions of acres that now lie idle under brush or forest.* In other words, every acre that will grow food for the people, and thereby reduce its cost and furnish sustenance for our increasing population and the teeming millions that are on the way to these shores, should be so employed; the remainder should grow timber that should be protected in its growth. Man and beast love the cooling shade, and the eye is pleased by the beauty of the wooded landscape. Therefore begin with the children and teach them to plant trees along the highways and byways and on the barren spots that will not produce food. Thus may we approach this problem rationally, with the object of gaining the greatest good for the greatest number for the longest period of time.

RATIO OF THE FORESTED AREA, OR MOUNTAIN WATERSHEDS, TO THE TOTAL WATERSHED.

I am of the opinion that not enough consideration has been given to the relative magnitude of the areas involved in the creation of floods. A flood in any given stream is usually caused by the precipitation over its entire watershed or over those of the major tributaries and is affected but comparatively little in a region like that of the Ohio basin by the precipitation over the extreme upper reaches, usually the forested area, or any other area that could be reforested without seriously encroaching upon the rich alluvial plains.

A critical examination of Chart C, which shows the entire river system of the Ohio basin and gives the exact limits of its boundaries, and which also indicates the elevations, shows what a comparatively small area in relation to the total catchment basin lies at

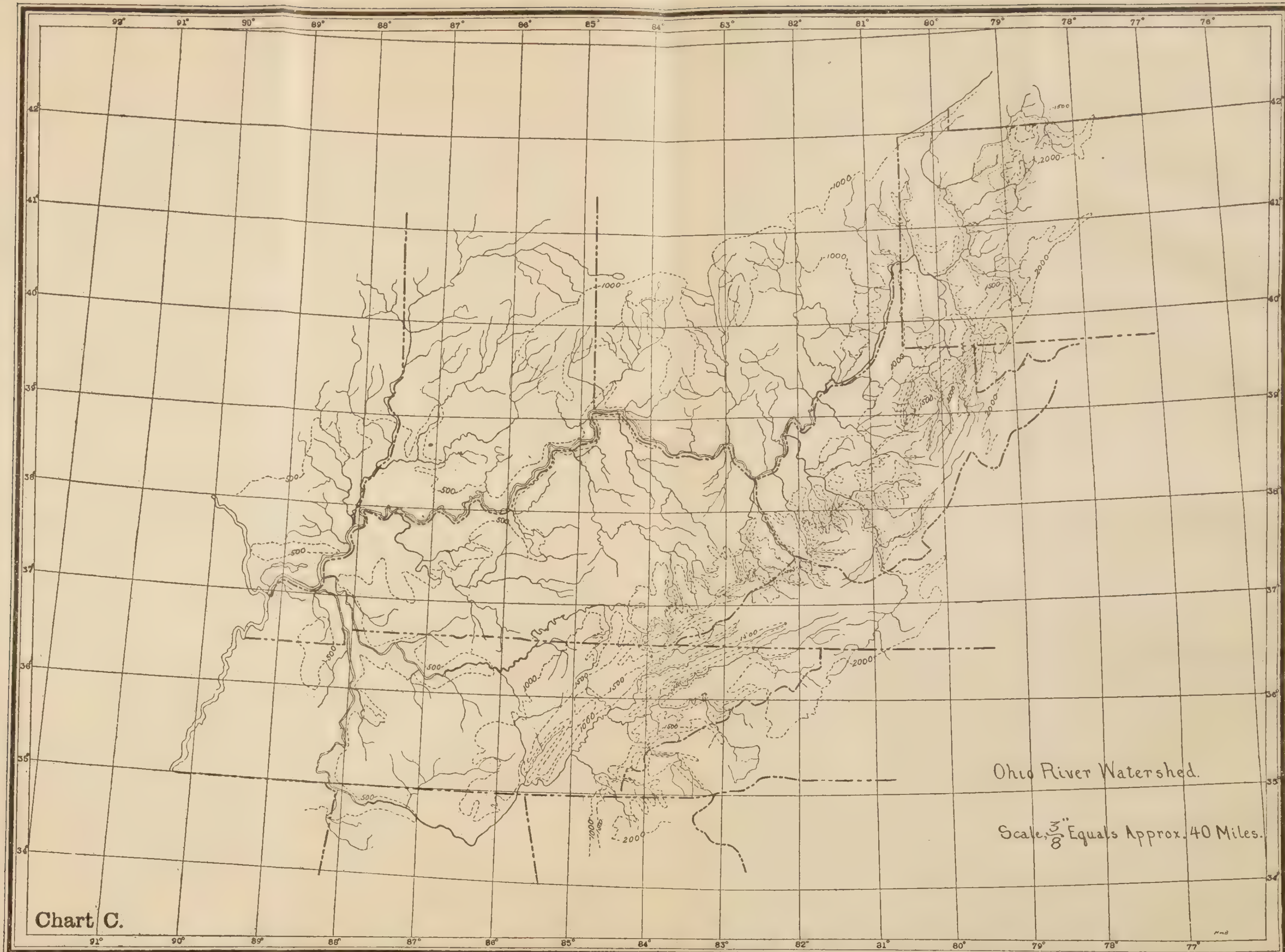

Chart C.

26320—10. (To face page 25.)

elevations of more than 1,000 or 1,500 feet above sea level. This chart furnishes a conclusive answer to those who believe that floods, except, of course, torrents in the mountain creeks, are caused by the precipitation on the comparatively small area of the watersheds at the headwaters of rivers. If it be granted that forests control the flow of streams, and I doubt that they do except as stated above, it will be necessary, in order to have an appreciable effect on navigable or other important rivers, to reforest areas many times in excess of anything that so far have been contemplated. *The rugged mountain slopes and tops, where land has little value, are unimportant as flood producers. It will be necessary actually to reforest the lower slopes and valleys where the land is of great value and where it should be devoted to agricultural purposes.* I can not escape this conclusion.

ARE FLOODS INCREASING?

Two papers have recently appeared, in both of which the argument is made that there is a marked tendency toward increasing flood frequency as a result of deforestation. The first of these papers in point of time was that of Mr. M. O. Leighton, Chief Hydrographer United States Geological Survey.[a] The second paper appeared in volume 2, Senate Document No. 676, beginning at page 112, and later as Forest Service Circular No. 176, January 11, 1910, under the signatures of Mr. William L. Hall, Assistant Forester, and Mr. Hu Maxwell, expert.

Before entering upon a discussion of these papers I wish to draw attention to the following statement in the last-named paper, page 3:

> * * * Both the Geological Survey and the Forest Service *have secured data*,[b] and the results warrant the statement that unmistakably floods are steadily on the increase in some of our most important rivers.

I wish to remark in connection with this statement that substantially all of the data used by the authors of the papers above mentioned were drawn from the records of the United States Weather Bureau.[c]

In Water-Supply Paper No. 234 the author has made a diagrammatic arrangement of data composed of annual and decennial means, whereby he shows an apparent progressive increase in the number of flood days at Wheeling, W. Va., and other points, without a proportionate increase in the amount of precipitation. It appears to me that his argument is defective in at least two particulars.

First. The flood or danger stage of the rivers at the various places discussed by him was long ago fixed by the Weather Bureau as being at the point where the river either overflows its banks or damages property adjacent thereto. Mr. Leighton has disregarded these points and arbitrarily assumed, for the purpose of his discussion, a

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[a] Report of National Conservation Commission, p. 95, and Water-Supply Paper No. 234.

[b] The italics are mine. (Author.)

[c] In Water-Supply Paper No. 234 the impression seems to be given that the author's researches and conclusions are based on a consideration of river discharge measurements. It is proper to state that river discharge measurements were begun under the direction of the United States Geological Survey in 1896 and that gauge readings of heights of rivers were begun by the United States Signal Service, now Weather Bureau, in 1874.

considerably lower stage in each case, so that his argument fails completely so far as it relates to flood frequency; for example, at Wheeling, W. Va., he assumes a stage of 20 feet, whereas the Ohio at that point is not in flood until a stage of 36 feet is reached. What the author is discussing is therefore not floods as such, but moderate stages of the river.

What appears to me to be a second defect in the author's argument lies in his acceptance of the total number of so-called flood days (20 feet or more being a day of flood) divided by the annual precipitation as an indication of flood intensity, since the annual rainfall, as he himself acknowledges,[a] bears little or no relation to floods. Greater floods may occur during a year of deficient precipitation than during one of excessive annual precipitation if the proper proportion of the rainfall be concentrated over a limited area in a limited time.

An examination of the data for Chattanooga, Tenn., given by that author, discloses the fact that there has not been any increase in the number of so-called flood days at that place. The average amount of precipitation for each daily river stage of 20 feet or more, as determined by him, is almost exactly the same for the two periods, 1884 to 1895 and 1896 to 1907, inclusive. But in the number of *actual flood days*, as determined by Professor Frankenfield, the official in charge of the Weather Bureau river and flood service, that is, 33 feet or over (and the river does not reach the danger or flood stage until it stands 33 feet above low water), there was a considerable decrease in the second period, in harmony with the precipitation.

I understand that when Mr. Leighton speaks of "the ratio of the annual number of days of flood to annual precipitation," he means the number of days (stage above 20 feet) in each year divided by the *total* precipitation for the year. Thus, if the number of flood days in any one year is 20, and the total precipitation is 40 inches, the ratio would be 20 divided by 40, or 0.5. These ratios are totaled in eleven-year periods and the average of each period obtained. The average for the first eleven years, as obtained by him, was 0.38, and of the second, 0.48, indicating, in his opinion, an increase in flood intensity during the second eleven-year period, as 1 inch of rain made only 0.38 of a flood during the first period, while in the second period 1 inch of rain made 0.48 of a flood. In other words, during the first eleven-year period 1 inch of rain made only 38 per cent of 20 feet of water, or 7.6 feet; while during the second period 1 inch of rain made 48 per cent of 20 feet of water, or 9.6 feet.

This line of reasoning leads to wrong conclusions, as it is certain that the ratios obtained by dividing the number of days that a certain gage reading was reached or maintained by the annual, or for that matter by any other, precipitation, without entering into the problem the exact height of water gives a meaningless result. It appears to me to be a fatal method of reasoning to take simply the number of days that a stage of 20 feet was reached, without regard to heights above 20 feet. Therefore, if on a certain number of days the gage reading was exactlv 20 feet, one would get precisely the same quotient as he would if on the same number of days the gage readings were largely in excess of 20 feet.

[a] Page 22, Water-Supply Paper No. 234.

I now come to that part of the discussion in Water-Supply Paper No. 234 which has been widely quoted by the adherents of the forest-control idea, viz, the proposition that, although the flood periods in the Tennessee have decreased in later years due to diminished precipitation, the flood tendencies have increased. This idea, like others that have been put forward in this connection, is important if it can be substantiated; and if it is proven, then it is incumbent upon the author of that paper to show that the increase is due to deforestation, which he does not do. I have no data as to the area that has been cleared or that has been allowed to revert to forests, but it can not be great in twelve years.

This whole matter of the influence of forests upon climate and floods is so important to the nation in planning a correct economic policy for the future that we should move cautiously and be sure that we are building safely and wisely. I am heart and soul with the noble men and women who, as individuals or collectively, are striving to protect and conserve in the interests of the whole people the nation's resources of forest and field and of minerals and water power, and in this opinion I am generally and strongly sustained by the scientific staff of the Weather Bureau.

With regard to the matters of which this paper specifically treats I wish for the freest, fullest, and fairest discussion and investigation, with the end in view of correcting error if there be such and of finding common ground upon which all well-meaning persons may stand. Those whose official reports differ from mine I believe to be as honest and as sincere in their investigations and conclusions as I know myself to be.

To return to Supply Paper No. 234, referred to above, I quote as follows from page 23:

> The results for the Tennessee basin cover twenty-four years, from 1884 to 1907, inclusive. * * * Summing up the flood-producing rains for the twenty-four year period, it is found that the total is 335, of which 313 occurred from December to May, inclusive, and the remaining 22 during the other portion of the year. It is apparent that the number of such rains from June to November is not sufficient to afford a basis of comparison. Therefore only the December to May floods will be considered. * * * On dividing the period covered by these 313 floods equally, two consecutive twelve-year periods are afforded, which give a basis of comparison. The floods in the later period, resulting from a given depth of storm precipitation, are clearly shown to be more severe than in the earlier period. The method of presentation further makes it possible to compute the increase in flood tendency due to deforestation in the Tennessee.
>
> * * * * * * *
>
> If we now divide the number of flood days by the number of storms the result will be the number of days per storm.

Days of flood per storm.

Period.	Storms in inches precipitated.							
	1 to 1.5.	1.5 to 2.	2 to 2.5.	2.5 to 3.	3 to 3.5.	3.5 to 4.	4 to 4.5.	4.5 to 5.
1884–1895	0.7	0.5	2.5	1.8	2.6	5	6	8.1
1896–1907	.4	.9	2.6	2.7	3.2	6	8	6.7
Percentage increase	− 43	80	4	50	22	20	33	− 17

The algebraic sum of the above percentages is 149 and the average is 18.75, which sums up the effects of deforestation on run-off from 1884 to 1907, inclusive.

I invite attention to the figures given in this table "Days of flood per storm." If the run-off in the second period was greater than in the first, due to deforestation, would not the latter show a uniform and progressive influence increasing as the amount of rainfall increased? How, then, does it happen that a decrease in run-off of 43 per cent is shown for rains of intensity 1 inch to 1.5 inches, while in the next higher grade of intensity, viz, 1.5 to 2 inches, an increase of 80 per cent is shown? In the next higher grade, viz, 2 to 2.5 inches, the increase drops to 4 per cent. These results founded, in my judgment, on incorrect premises, are both inconsistent and meaningless. To "divide the number of flood days by the number of storms" gives no valuable quotient, for the gage readings selected as floods are not floods, but only moderate stages, and no account is taken of the actual height of the water, and while the conclusion is reached that there is an increase in flood intensity of 18.75 per cent in the Tennessee basin in the past twelve years due to deforestation, no records or other evidence are presented that there is not as much forest area in this basin as there was twelve years ago; or that, if there is a decrease, it would be sufficient to account for such a large increase in flood intensity.

But—and here is the most important matter in the consideration of Mr. Leighton's conclusions—no matter how complete the data may be, or how fundamentally sound and fair its collation and grouping, the comparison, the one with the other, of such short periods as those measured by only twelve years, can not give results with regard to changes in climate and floods that will permit the most skilled meteorologist or engineer to draw fundamental conclusions that can have any value. Precisely the same amount of rain falling in the two periods and no change whatever in forest or cultivated area might produce largely differing results on floods, depending on the sequence with which it fell over the different tributaries and how it was concentrated or scattered, and on many other complicated conditions of run-off, such as the coinciding of the flood volume from one tributary with that of another, instead of each passing down the main stream at different times.

There is also the difficulty of securing accurate precipitation data. Whenever the height of the gage is altered or other change made in its environment that disturbs the flow of the air currents the readings of one period may not fairly be compared the one with the other. These defects vitiate the precipitation data of many stations of the Weather Bureau, especially those in large and growing cities, and can only be remedied by the Government controlling for a long period of years an area at each station so large that it can determine the exposure and keep it constant.

Another way of comparing the precipitation and the river stages of the Tennessee basins.—I give in the following table the rainfall at Chattanooga and Knoxville separately for the months December to May, inclusive, for each of the twenty-four years considered in Water-Supply Paper No. 234; also the total number of days of river stages of 20 feet and above on the Chattanooga gage. The rainfall so tabulated includes only the heavy rains, and the arrangement according to intensity is precisely the same as that followed in Water-Supply Paper No. 234.

Heavy rains at Chattanooga and Knoxville, Tenn., during six months of each year (December, 1883, to May, 1907).

December-May, 1883-1907.	1 to 1.5 inches.		1.5 to 2 inches.		2 to 2.5 inches.		2.5 to 3 inches.	
	Number of rains.	Total amount.	Number of rains.	Total amount.	Number of rains.	Total amount.	Number of rains.	Total amount.
First half:								
Chattanooga	57	68.65	16	27.54	8	17.83	13	35.67
Knoxville	44	51.01	26	45.59	13	29.44	4	11.04
Total	101	119.66	42	73.13	21	47.27	17	46.71
Mean								
Second half:								
Chattanooga	52	62.48	11	18.18	12	26.28	9	24.13
Knoxville	48	55.87	21	35.47	10	22.19	10	27.48
Total	100	118.35	32	53.65	22	48.47	19	51.61
Mean								

December-May, 1883-1907.	3 to 3.5 inches.		3.5 to 4 inches.		4 to 4.5 inches.		4.5 + inches.		Grand total.
	Number of rains.	Total amount.	Number of rains.	Total amount.	Number of rains.	Total amount.	Number of rains.	Total amount.	
First half:									
Chattanooga	4	13.45	4	15.07	2	8.58	6	33.43	220.22
Knoxville	4	12.70	1	3.78	2	8.79	4	22.04	184.39
Total	8	26.15	5	18.85	4	17.37	10	55.47	404.61
Mean									202.30
Second half:									
Chattanooga	4	13.41	2	7.71	2	8.38	4	23.27	183.84
Knoxville	5	16.17	2	7.46					164.64
Total	9	29.58	4	15.17	2	8.38	4	23.27	348.48
Mean									174.24

The data of the above table have been divided into two periods of twelve years each, with the following results:

First period.

Total number of heavy rains at Chattanooga	110
Total number of heavy rains at Knoxville	100
Total	210

Total amount of the above heavy rains as per table, 404.61 inches.

Dividing this total by two, to get the approximate average of the heavy rains for the watershed, we get 202.30 inches.

Total number of days with stages of 20 feet or more at Chattanooga 166

Dividing the amount of the heavy rains in the watershed by the number of days with a river stage of 20 feet or over, we get $\frac{202.30}{166}=1.220$ inches as the amount of rainfall that probably produced one day of a stage of water in the river of 20 feet or more.

Second period.

Total number of heavy rains at Chattanooga	96
Total number of heavy rains at Knoxville	96
Total	192

Total amount of the above heavy rains, 348.48 inches.

Dividing this total as before, we get as an approximate average of the heavy rains in the watershed 174.24 inches.

Total number of days with stages of 20 feet or over in the river	141

Dividing as before, we get as the probable amount of rainfall in the second period required to produce a day of 20 feet or over in the river, 1.236 inches, as against 1.220 inches in the first period.

The difference between the line of reasoning employed in getting the above results and those given in Water-Supply Paper No. 234 is that the author of the latter attempts to differentiate between the stages produced by rains of varying intensity and to assign to such rains a given number of so-called "flood days," while in this paper the assertion is made that in the first period there were a given number of days with a stage of 20 feet and over in the river, and that during that time the heavy or flood-producing rains amounted to so much. Dividing, then, the total of the flood-producing rains by the corresponding number of days with a stage of 20 feet or over, the results given above are reached, viz, that for the first period it took 1.22 inches of rainfall to produce a day with a 20-foot stage in the river. These figures contradict the contention that an equal depth of rain in the last period as compared with the first produced more severe floods in the river. I only present them to show how easy it is to arrange data so as to prove both sides to a question. While this line of inquiry is open to less objection than that followed by Leighton, it does conform to the plan of the latter in so far as it uses the number of days that the river stood at or above 20 feet, instead of taking into consideration the actual height of the water. The most that can be said is that this form of inquiry shows no increase in flood intensity.

Rainfall and run-off of the Ohio Basin.—We now come to a different and more reliable form of investigating this question of the relation of precipitation to run-off.

We have no direct method of measuring the run-off, but we can reach a fair approximation to it by a comparison of the rainfall and river data for any given watershed. If, for example, the surface conditions over any considerable part of a watershed have been materially changed by deforestation or other means, and if, as claimed, such change operates to increase the run-off, then the flow of water in the streams after the change has been brought about should be greater for equal depth of precipitation. This method is a rough one, to be sure, but it appears to be the only one permitted by the records as they exist.

Cincinnati, Ohio, has been chosen as the point whose river observations are best adapted to our purpose, although some objection to that place lies in the constriction of the natural river channel caused by the encroachment on the banks of the stream by various artificial structures. The station at Pittsburg, Pa., is better situated for comparative purposes, but the low-water stages at that place of

late years have been vitiated by the construction of the Davis Island dam. The construction of dams at several places in other rivers has lowered the value of low river gauge readings for comparative purposes.

In the tables which follow I have given the actual mean monthly stage of the Ohio at Cincinnati for every month of the period 1871 to 1908. The average of these monthly means has been computed for the first period of nineteen years; these averages have been summed up for the twelve months of the year, and that sum has been divided by twelve in order to get the annual mean. The number so obtained, 17.3 feet, is therefore the average stage of the river for the entire nineteen years, as computed from all of the daily stages for that period. In like manner the average stage of the river for the second period of years has been computed and is given in the following table:

Mean monthly and annual river stages in the Ohio River at Cincinnati, Ohio, for the period 1871–1908.

[In feet and tenths.]

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
1871	14.6	23.1	25.3	16.5	21.8	8.2	7.1	5.1	5.4	3.2	6.5	7.3	....
1872	14.0	14.1	13.3	25.8	11.8	10.9	11.9	8.4	5.1	4.2	10.0	10.5	....
1873	22.6	29.4	21.4	29.2	25.6	9.2	13.3	10.0	6.6	7.3	15.6	28.6	....
1874	29.7	27.9	25.7	31.6	20.7	7.8	6.1	9.0	4.2	5.4	4.6	13.4	....
1875	18.3	16.7	34.4	23.9	14.7	11.8	25.0	26.7	5.1	7.4	15.9	24.3	....
1876	31.4	33.9	25.6	25.4	18.2	10.1	11.8	10.6	16.8	10.7	11.7	12.1	....
1877	28.1	18.4	28.0	23.1	17.4	12.1	11.3	5.5	6.2	5.1	12.1	15.1	....
1878	20.0	24.2	24.2	14.5	22.0	12.5	9.0	10.6	13.7	6.0	14.8	29.1	....
1879	23.2	26.6	32.8	22.9	11.4	7.1	5.6	9.9	6.9	3.2	5.4	19.2	....
1880	29.2	28.3	35.2	24.6	15.8	14.0	9.4	8.4	7.0	4.6	10.4	18.1	....
1881	20.7	33.1	27.2	29.4	16.1	16.5	7.8	4.9	3.6	4.4	14.8	25.0	....
1882	42.0	44.0	34.2	18.2	30.6	26.5	16.9	13.7	13.9	9.0	8.7	12.7	....
1883	18.1	48.6	20.3	36.0	49.0	61.5	12.9	8.7	4.4	7.9	38.0	32.2	....
1884	24.5	54.4	36.5	24.5	17.5	11.3	8.5	6.5	3.6	3.9	4.4	12.2	....
1885	25.6	15.6	17.1	26.5	15.0	14.7	6.8	12.5	11.0	8.5	15.5	18.1	....
1886	24.7	26.0	20.6	37.4	22.0	15.5	13.8	10.0	5.4	5.2	12.2	19.4	....
1887	20.4	48.4	29.4	24.0	20.6	14.8	5.7	4.9	3.3	3.3	3.6	6.1	....
1888	20.2	20.1	23.0	23.8	13.8	10.4	14.6	12.1	16.4	17.9	27.4	16.2	....
1889	25.2	24.1	20.9	19.0	16.0	25.2	18.5	12.2	6.7	8.0	24.6	23.9	....
1890	33.0	37.9	46.0	31.7	32.5	19.8	10.8	9.7	20.8	21.2	24.2	17.3	....
1891	31.8	46.8	37.2	30.6	9.8	18.9	13.0	11.2	9.7	4.9	9.6	18.9	....
1892	23.8	24.5	25.4	31.5	25.2	23.1	11.6	7.7	5.7	4.3	6.4	11.1	....
1893	12.7	41.1	25.8	26.8	36.1	14.9	8.3	4.8	7.2	10.5	9.5	16.5	....
1894	17.3	27.2	22.6	19.1	16.9	12.3	5.6	4.3	4.8	4.6	6.6	12.0	....
1895	28.3	13.9	27.4	24.4	12.3	6.5	7.5	6.1	4.9	3.0	3.4	9.4	....
1896	14.1	23.6	22.5	26.1	12.3	11.7	22.1	20.1	6.7	14.8	13.8	19.7	....
1897	14.4	36.3	40.3	26.3	23.1	12.8	13.9	10.3	4.8	3.5	8.0	17.8	....
1898	35.3	25.0	31.3	27.1	23.7	11.7	8.6	20.2	7.7	10.1	17.1	18.7	....
1899	31.8	25.9	40.1	26.7	17.4	13.6	8.4	8.0	5.1	3.9	6.4	13.4	....
1900	18.7	24.5	28.9	17.8	11.2	10.8	9.5	7.9	5.0	4.3	10.3	19.2	....
1901	15.8	13.8	22.2	39.5	25.5	28.1	13.1	9.6	10.9	6.4	5.6	20.6	....
1902	19.9	19.2	37.2	26.7	13.6	11.0	19.4	9.9	4.4	7.6	6.3	26.9	....
1903	23.1	39.7	42.5	32.9	12.0	13.5	12.7	6.7	8.2	6.6	7.3	9.6	....
1904	19.4	20.3	34.6	26.6	20.1	16.2	13.5	6.3	5.0	3.8	4.2	4.6	....
1905	14.9	21.4	33.3	19.7	25.2	16.3	15.8	12.9	10.2	10.8	12.0	25.6	....
1906	26.8	13.9	26.3	30.3	14.3	12.5	10.1	14.4	10.1	13.3	15.8	23.3	....
1907	45.7	22.0	40.1	23.9	22.5	27.2	18.3	13.5	12.1	10.6	17.0	19.4	....
1908	22.0	32.2	41.9	35.8	30.8	12.9	10.0	8.6	4.4	3.6	4.8	5.2	....
Mean:													
1871–1889	23.8	29.3	26.1	25.1	20.0	15.8	11.4	10.0	7.6	6.6	13.5	18.1	17.3
1890–1908	23.6	26.8	32.9	27.6	20.2	15.5	12.2	10.1	7.8	7.8	9.9	16.3	17.6
1871–1908	23.7	28.1	29.5	26.3	20.1	15.6	11.8	10.0	7.7	7.2	11.7	17.2	17.4

The average precipitation for the watershed has not been so easily obtained. Only in exceptional cases are continuous measurements of precipitation available for comparative studies. The government records in large cities are of necessity made from gauges whose imme-

diate environment has been changed repeatedly in the course of a long series of years, and it was for this reason that the rain-gauge records from Cincinnati and Pittsburg were ignored. The points selected—viz, North Lewisburg and Portsmouth, Ohio, and Confluence and Franklin, Pa.—are the best and practically the only long-period records available in this watershed. A better distribution throughout the watershed would have been preferred, but it is not possible to obtain it. The precipitation, like the river stages, has been computed in periods of nineteen years each. The tables follow:

Annual precipitation in the Ohio watershed for the period 1871 to 1908, inclusive.

[In inches and tenths.]

Year.	North Lewisburg, Ohio.	Portsmouth, Ohio.	Confluence, Pa.	Franklin, Pa.	For the watershed.
1871	30.6	30.7	[a] 27.7	34.7	....
1872	28.6	31.1	[a] 31.0	41.5	....
1873	37.2	46.2	[a] 41.4	54.9	....
1874	34.0	38.3	[a] 39.4	47.4	....
1875	43.2	45.7	39.1	45.8	....
1876	42.0	41.2	46.4	46.9	....
1877	37.3	35.0	45.0	43.5	....
1878	44.0	29.9	41.1	40.1	....
1879	48.4	35.6	38.8	37.7	....
1880	46.4	49.0	49.2	34.0	....
1881	44.0	40.8	41.4	39.1	....
1882	45.8	56.2	55.1	45.8	....
1883	48.9	48.5	49.8	41.3	....
1884	34.3	42.3	42.1	42.0	....
1885	38.8	37.3	39.3	44.6	....
1886	40.6	45.3	44.1	38.8	....
1887	35.0	40.7	[b] 31.2	40.8	....
1888	47.6	48.3	[b] 47.3	49.2	....
1889	30.8	39.3	40.0	43.8	....
1890	45.2	57.6	60.1	58.5	....
1891	44.2	42.8	57.5	[c] 51.4	....
1892	40.2	44.1	38.4	[c] 47.6	....
1893	49.1	37.9	43.4	[c] 48.7	....
1894	39.6	36.2	42.1	[c] 43.3	....
1895	29.0	31.2	35.1	[c] 33.5	....
1896	48.3	39.9	50.2	[c] 41.2	....
1897	43.5	49.1	45.8	39.6	....
1898	52.2	48.1	53.2	39.1	....
1899	34.0	42.9	48.9	32.8	....
1900	32.5	34.6	44.0	31.7	....
1901	29.6	39.7	41.2	42.2	....
1902	36.6	37.2	45.9	39.1	....
1903	28.7	37.3	38.3	45.6	....
1904	35.4	29.2	31.4	40.8	....
1905	[d] 35.1	43.3	51.1	45.1	....
1906	[d] 33.7	44.4	48.7	[e] 40.2	....
1907	[d] 37.6	42.3	55.8	[e] 42.3	....
1908	30.1	40.0	42.1	[e] 41.1	....
Mean:					
1871–1889	39.8	41.1	41.5	42.7	41.3
1890–1908	38.1	40.9	46.0	42.3	41.8
Mean for entire period	39.0	41.0	43.8	42.5	41.6

[a] Record of Pittsburg, Pa.
[b] Record of Lock No. 4, Pennsylvania.
[c] Record of Warren, Pa.
[d] Record of Columbus, Ohio.
[e] Record of Parkers, Pa.

Summarizing the above, we have:

Average stage of the Ohio River at Cincinnati, Ohio:	Feet.
1871 to 1889	17.3
1890 to 1908	17.5
Average precipitation in the Ohio watershed, as determined from the stations above named:	Inches.
1871 to 1889	41.3
1890 to 1908	41.8

I consider that the results secured from the discussion of the precipitation and the gauge readings in the Ohio basin, as given in the foregoing tables, form one of the most important contributions made by this paper. Here we have avoided the using of indefinite and meaningless data, and have taken the longest period of time for which accurate records can be secured on a watershed that is suitable for this line of inquiry. We have not simply counted the number of days that the river stood above some arbitrarily selected stage without taking into consideration the exact height of the river. Neither have we divided the gauge readings by some arbitrarily selected portion of precipitation data. On the contrary, we have endeavored to profit by the errors of previous investigations, and to lay the foundation of an inquiry that would mean something when we reached the end of our computations. For this reason we have selected a typical station on the main stream that drains the Ohio Basin and have discussed rainfall data that are the most accurate of any in the region, having been subject to less errors due to varying environments. Any deductions made from an inquiry founded with less care, or from data of a less degree of accuracy, must bring results from which it would be unsafe to form definite conclusions.

Now let us see what is the result. The average stage of the river for the first nineteen years is 17.3 feet, and for the last nineteen years 17.5 feet, showing that there is practically no change in the run-off of the Ohio Basin between the first period and the last. When we examine the average precipitation over the watershed that is drained by this river we find that for the first nineteen years it was 41.3 inches, and for the last nineteen-year period it was 41.8 inches, a slight increase in precipitation for the latter period that agrees precisely with the slightly greater average flow of water. There is a perfect agreement here between the precipitation and the flow of the stream. I do not know what has been the area deforested in this valley during the thirty-eight years under discussion, but whatever it is it seems to be apparent that such altering of the relation of forest area to cultivated area has had no appreciable effect on the flow of the Ohio River. I am aware of the fact that by the studying of short periods of data on small tributary streams, and especially by the grouping of data dissimilar from what is employed in this discussion, all manner of results may be shown.

I believe that the reader will acknowledge that I have shown in the several preceding paragraphs that the average discharge of the Ohio River, where I presume deforestation has been as great as in any other part of the country during recent time, has not changed for a period of thirty-eight years, except as caused by precipitation. It will now be interesting to know how the two periods compare with regard to extremely high water and extremely low water, and this will be discussed in the coming pages.

High water and low water on the rivers of the Ohio basin.—I had Prof. H. C. Frankenfield, Chief of the River and Flood Division of the Weather Bureau, compile the data from one station on the Cumberland, three on the Tennessee, and five on the Ohio, and establish the average high water for the four wet months, January to April, and the average low water for the four dry months, July to October. He then

took the departure from the normal, both for the precipitation and for the height of the rivers, and found that *the average high water was no higher and the average low water was no lower for the last half of the period than for the first half.* The differences were so slight as to be inappreciable, but what changes occurred were in favor of the low water being slightly higher and the flood waters slightly less. There were variations in the periods and intensities of floods that bear a direct and proper relation to the precipitation. In making his report, Professor Frankenfield points to the fact that the low-water stages at Pittsburg, Pa., and Nashville, Tenn., are not fairly comparable with those of the other stations on account of permanent pool stages caused by dams operated during the low-water season for purposes of navigation. The first dam below Pittsburg was placed in operation in 1885, and that at Nashville in 1904. The effect of these dams is to furnish higher low-water stages than would result without them. The effect upon the normal low-water stage at Nashville was not marked, but at Pittsburg it was perceptible. However, in his conclusions he did not make allowance for the slightly higher low-water stages at Pittsburg on account of the dam, but when included with the other stages of the river this defect probably is not apparent.

According to our line of reasoning, which we believe to be fair and conservative, it is shown that the average discharge of the Ohio River is not greater as the result of deforestation during the last nineteen years than during the preceding like period, and that the average high water in the rivers of the entire basin, which includes the Tennessee, the Cumberland, and the Ohio, is not higher and the low water is not lower.

Are real flood stages more numerous than formerly?—The next line of inquiry will be for the purpose of determining whether or not there has been in recent time an increase in the number of days that these rivers were at or above the flood stage, and in making this inquiry *exact flood stages* will be used, not simply gauge readings less than flood. Again I called on Professor Frankenfield to prepare the necessary data. As the data was not complete with regard to flood stages for the first ten years of the period that we have been discussing, he took a period of ten years less in length, beginning with 1879, and as the result of his computations we have the following table:

Number of days in each year that the rivers were at or above the flood stage.

[Flood stage given with name of station.]

	Cumberland River, Nashville, Tenn.	Tennessee River.			Ohio River.					Total.
		Chattanooga, Tenn.	Florence, Ala.	Johnsonville, Tenn.	Pittsburg, Pa.	Cincinnati, Ohio.	Louisville, Ky.	Evansville, Ind.	Cairo, Ill.	
Flood stage in feet	40	33	16	21	22	50	28	35	45	
Year.										
1879	3	3	10	[a] 19	....	....	....	4	....	....
1880	19	4	19	[a] 51	....	4	4	31	....	....
1881	....	....	4	([b])	3	2	....	11	6	....
1882	30	9	44	80	....	9	8	63	56	....
1883	6	4	15	[a] 73	2	16	15	[a] 34	21	....
1884	25	12	42	[a] 91	3	19	19	51	40	....
1885	....	....	10	20	1	....	....	5	....	....
1886	14	11	17	31	1	12	11	19	21	....
1887	11	....	10	44	....	13	11	53	32	....
1888	....	....	13	27	....	....	....	3	5	....
1889	....	....	8	12	....	....	....	....	....	....
1890	14	5	16	[a] 55	2	14	17	65	39	....
1891	15	9	35	63	4	8	6	67	13	....
1892	....	5	18	40	1	....	....	8	30	....
1893	3	1	17	44	2	10	2	28	18	....
1894	3	....	2	14	1	....	....	....	....	....
1895	....	....	4	15	1	....	....	3	....	....
1896	6	4	7	18	....	....	....	6	....	....
1897	16	9	29	48	2	8	7	36	48	....
1898	....	....	....	20	3	15	15	37	17	....
1899	2	13	26	66	1	9	5	39	26	....
1900	....	....	4	18	1	....	....	....	....	....
1901	....	1	17	42	3	9	7	12	....	....
1902	12	6	30	50	3	4	....	26	....	....
1903	1	....	31	58	3	8	1	45	25	....
1904	....	....	3	9	4	....	....	19	15	....
1905	....	....	3	13	5	....	....	4	....	....
1906	....	1	....	22	....	1	....	11	12	....
1907	....	....	....	24	4	22	22	46	23	....
1908	....	....	3	18	3	12	5	57	11	....
Total, 1879–1893	140	63	278	650	19	107	93	442	281	2,073
Total, 1894–1908	40	34	159	435	34	88	62	341	177	1,370
Grand total	180	97	437	1,085	53	195	155	783	458	3,443

[a] Data incomplete. [b] Data missing for this year.

	Days.
Total 1879–1893	2,073
Total 1894–1908	1,370
Excess of first period over second period	703
Average per year, 1879–1893	138.2
Average per year, 1894–1908	91.3
Excess per year first period over second period	46.9

From the foregoing it will be seen that in the first fourteen years there were 2,073 days that the Cumberland River at Nashville; the Ohio at Pittsburg, Cincinnati, Louisville, Evansville, and Cairo; the Tennessee at Chattanooga, Florence, and Johnsonville, were at the flood stage—that is, they were bank full or overflowing. During the last fourteen years the number of such days is 1,370, an excess in the first fourteen years of 703 days, or an average of 46.9 days excess per year in the first period over the second.

Now, I would guard against unsafe conclusions from these results. The fact is that abnormally heavy precipitation for several years in

the forepart of the first fourteen-year period, especially that which caused the famous 1882 flood, places such a preponderance of flood days in the first period that it would be unfair to claim that there has been any such permanent decrease in flood intensity as is shown by this table. It is given for what it is worth, and further to emphasize the fact that conclusions on which fundamental theories or policies are based should not be founded upon short-period data. While I am strongly of the opinion that there is no permanent increase in the number of flood days for the rivers of the United States as a whole, between the last fifty years and the preceding fifty years, I should not rely upon such short-period data as is contained in this table to sustain my belief. But if these data of twenty-eight years, which shows such a marked decrease in flood intensity of the rivers of the Ohio Valley, and which are founded upon unquestionably accurate data, are not sufficient evidence for a scientific man to claim statistical proof of the decrease of floods, what shall one say of the statements made by Messrs. Hall and Maxwell, of the Forest Service, in volume 2, Senate Document No. 676, in a paper on "Surface conditions and stream flow," which begins at page 112, as follows:

THE TENDENCY IS TOWARD INCREASED FLOODS.

On the Potomac River, for which measurements are given for eighteen years, the number of floods during the first half of the period was 19; during the second half, 26; while the number of days of flood in the first half was 33, and in the second half, 57.

On the Monongahela River measurements are given for twenty-two years. During the first half of the period there were 30 floods; during the second half, 52. The number of days of flood during the first half of the period was 55; during the second half, 100.

On the Ohio River measurements are given for twenty-six years. During the first half of the period there were 46 floods; during the second half, 59. The number of days of flood during the first half was 143, during the second half, 188.

On the Cumberland River measurements were given for eighteen years. During the first half of the period there were 32 floods; during the second half, 43. The number of days of flood during the first half was 89; during the second half, 102.

On the Wateree River measurements have gone on for sixteen years. In the first half of the period the number of floods was 46; in the second half, 70. The number of days of flood in the first half of the period was 147; in the last half, 187.

On the Savannah River measurements have continued for eighteen years. During the first half of the period the number of floods was 47; during the second half, 58. The number of days of flood during the first period was 116; during the second half, 170.

On the Allegheny River measurements are given for thirty-four years. During the first half of the period there were 39 floods; during the second half, 53. The number of days of flood during the first half was 92; during the second half, 131.

On the Tennessee River measurements have been taken for thirty-four years. During the first half of the period there were 32 floods, during the second half, 33. The number of days of flood during the first half was 173; during the second half (in this case there was a falling-off), 137.

The conclusions arrived at by the authors are, in my judgment, faulty, because:

First. The shortness of the period of observations at the majority of the stations discussed.

Second. The arbitrary assumption as flood stages of certain heights of water much below that necessary to cause a flood.

As to the period of observations: Those of us who are accustomed to the computation of normals or mean values have always realized how little value they possess unless obtained from data covering a long period of years. This is true of temperature normals, which vary but little from year to year. How much more must it be true of precipitation and river-stage data, with their wide extremes and

irregular fluctuations? As a matter of fact any average of river conditions, or any mean annual precipitation determined from ten or fifteen years' observations, would be of little or no value in a discussion of this character, and when two of these short-period normals are compared with each other the actual errors would probably be multiplied.

Second, opinions may differ, of course, as to what constitutes a flood, but the Weather Bureau (and engineers generally) have uniformly defined a river to be in flood when it reached a stage above which damage would be caused, practically the bank-full stage. This being so, it would appear reasonable and proper that this definition of the term should be accepted and data discussed accordingly. If the flood stage at a given point is 18 feet, an assumption of a lower or a higher figure for purposes of investigating the frequency of floods must necessarily be misleading.

I will now take up the rivers in the order named in the quotation and give the net result of Professor Frankenfield's inquiry as to the number of *real* floods:

Potomac.—On the Potomac River the number of floods has not increased, but there were more days of a 12-foot stage in the last period than in the first. The explanation of this increase is found in the precipitation.

Monongahela.—On the Monongahela River, using data for Lock No. 4, Pennsylvania, 40 miles above Pittsburg, there were two more floods in the second period as compared with the first, the figures being 13 and 11, respectively. Two of the days of flood occurred in March, 1907, as a result of abnormal weather conditions over the watershed.

Ohio at Wheeling.—There was an increase in the number of floods at Wheeling, but said increase is not shown farther down the river than Parkersburg. It (the increase) disappeared below the mouth of the Great Kanawha, as indicated by the Cincinnati records. The reason ascribed for this increase in flood frequency is an increase in short-period heavy rains. The same conditions appear to have obtained in the Allegheny at Freeport.

Cumberland.—There has been no increase in flood conditions in the Cumberland.

Wateree.—There was a marked increase in the number of flood days on this river during the second period. On the other hand, the precipitation in the watershed shows a like marked increase.

Savannah.—The record for the Savannah River at Augusta shows a marked decrease in the second period as compared with the first.

Allegheny at Freeport.—See Wheeling.

Tennessee.—See detailed discussion on this river in another part of this paper.

CONCLUSIONS.

(1) Any marked climatic changes that may have taken place are of wide extent and not local, are appreciable only when measured in geologic periods, and evidence is strong that the cutting away of the forests has had nothing to do with the creating or the augmenting of droughts in any part of the world.

(2) Precipitation controls forestation, but forestation has little or no effect upon precipitation.

(3) Any local modification of temperature and humidity caused by the presence or absence of forest covering, the buildings of villages and cities, etc., could not extend upward more than a few hundred feet, and in this stratum of air saturation rarely occurs, even during rainfall, whereas precipitation is the result of conditions that exist at such altitudes as not to be controlled or affected by the small thermal irregularities of the surface air.

(4) During the period of accurate observations, the amount of precipitation has not increased or decreased to an extent worthy of consideration.

(5) Floods are caused by excessive precipitation, and the source of the precipitation over the central and eastern portions of the United States is the vapor borne by the warm southerly winds from the Gulf of Mexico and the adjacent ocean into the interior of the country, but little from the Pacific Ocean crossing the Rocky Mountains.

(6) Compared with the total area of a given watershed, that of the headwaters is usually small and, except locally in mountain streams, their run-off would not be sufficient to cause floods, even if deforestation allowed a greater and quicker run-off. Granting for the sake of argument that deforestation might be responsible for general floods over a watershed, it would be necessary, in order to prevent them, to reforest the lower levels with their vastly greater areas, an impossibility unless valuable agricultural lands are to be abandoned as food-producing areas.

(7) The run-off of our rivers is not materially affected by any other factor than the precipitation.

(8) The high waters are not higher, and the low waters are not lower than formerly. In fact, there appears to be a tendency in late years toward a slightly better low-water flow in summer.

(9) Floods are not of greater frequency and longer duration than formerly.

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